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Evaluation of Sediment Contamination in Pueblo Canyon

Reaches P-1, P-2, P-3, and P-4

Environmental Restoration Project
A Department of Energy Environmental Cleanup Program

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EXECUTIVE SUMMARY

This interim report presents the results of investigations on contaminated sediments in Pueblo Canyon and recommendations concerning potential additional assessments, sampling and analysis, and remedial actions. The objectives of this work include defining the nature and extent of contaminants within the sediments of Pueblo Canyon, evaluating potential human health and ecological risk related to these contaminants, and evaluating the processes that redistribute these contaminants and the future consequences of this redistribution. The risk assessments presented in this report are preliminary and are intended to identify if there is a need for immediate remedial action or additional data collection. More comprehensive risk assessments will be presented in future reports on Pueblo and Los Alamos Canyons that will incorporate the results of ongoing groundwater investigations and additional sediment investigations.

Pueblo Canyon has received contaminants from multiple potential release sites (PRSs) within the watershed. The most significant contaminant source was former Technical Area (TA) -45, where radioactive effluent was discharged between 1944 and 1964 into Acid Canyon, a small tributary to Pueblo Canyon. Other PRSs that may have contributed contaminants to Pueblo Canyon are located in TA-0, TA-31, and TA-73, and contaminants may also have originated from residential and commercial areas in the Los Alamos townsite.

The technical approach followed in this investigation focused on detailed evaluation of contamination within four sections of Pueblo Canyon, called “reaches.” These reaches were selected (1) to encompass the range of potential risk related to contaminated sediments along the full length of the canyon downstream from the PRSs and (2) to allow testing and refinement of a conceptual model describing the distribution and transport of contaminants. Phased field investigations included detailed geomorphic mapping and characterization of post-1942 sediments, those sediments potentially containing contaminants resulting from Laboratory operations. An evaluation of data collected during each phase was used to revise the conceptual model, identify key uncertainties, and focus subsequent data collection.

The most significant chemical of potential concern (COPC) in the sediments of Pueblo Canyon with regard to potential human health risk is plutonium-239,240. Plutonium-239,240 and other COPCs have been distributed by floods along the full length of Pueblo Canyon downstream from Acid Canyon, a distance of more than 10 km, and have been dispersed laterally away from the stream channel for distances varying from less than 5 m to greater than 100 m. Concentrations of plutonium in sediments transported by floods were highest during the period of effluent releases, and concentrations dropped rapidly after releases stopped. Concentrations have been stable or have declined since 1965, indicating that concentrations will not increase in the future. Plutonium concentrations are higher in relatively fine-grained sediment deposits of a given age than in associated coarse-grained sediment deposits; therefore, potential risk is higher in those areas where fine-grained sediments have been deposited. Because of these particle-size effects and time-dependent changes in contamination, plutonium-239,240 concentrations are highest in fine-grained sediments that were deposited between 1942 and 1965. The highest concentrations have been found close to Acid Canyon, but fine-grained sediments with relatively high plutonium concentration have also been found many kilometers downstream in the eastern part of Pueblo Canyon.

The inventory of plutonium-239,240 in Pueblo Canyon sediments shows geographic patterns that are partly different from those related to plutonium concentration. Potential remedial actions that are designed to reduce either the total plutonium inventory or the part of the plutonium inventory most

susceptible to remobilization in floods would therefore target different areas than potential remedial actions designed to reduce risk at a site. Specifically, the largest part of the total plutonium inventory is within the eastern part of Pueblo Canyon in exceptionally large deposits of coarse-grained sediment where plutonium concentrations are lower than in adjacent fine-grained sediment.

Other COPCs identified in the sediments of Pueblo Canyon include 5 radionuclides, 8 inorganic chemicals, and 29 organic chemicals. Plutonium-239,240 is measured at concentrations up to 7000 times the background value. All other COPCs are found at much lower concentrations relative to background or detection limits. The concentrations of americium-241, plutonium-238, and perhaps tritium are positively correlated with plutonium-239,240 concentrations, indicating collocation of these COPCs and similar histories of release and transport. However, the concentrations of the remaining COPCs do not display the same collocation with plutonium-239,240, and their sources and distributions are more poorly defined. Collection of additional data on some of these COPCs may be required to complete future human health and ecological risk assessments.

The levels of contamination in Pueblo Canyon sediments do not present a significant human health risk under the conditions of present-day land use, including scenarios for trail users, resource users, and construction workers. Thus, no immediate remedial action is required with regard to potential human health risk. In addition, because concentrations of contaminants in sediments carried by floods are not increasing over time and present levels of contamination have not been shown to either cause an unacceptable risk in downstream areas or exceed regulatory standards, no immediate remedial action is required in the context of future remobilization of contaminated sediments. Thus, possible decisions to implement any remedial action in Pueblo Canyon should be made in the context of future assessments and/or future policy directives.

1.0 INTRODUCTION

1.1 Purpose

This interim report describes sediment investigations conducted in Pueblo Canyon (Figure 1.1-1) in 1996, 1997, and 1998 by personnel from the Canyons Focus Area (formerly Field Unit 4) as part of the Los Alamos National Laboratory ("the Laboratory") Environmental Restoration (ER) Project. Investigations were focused on four reaches of the canyon following the technical strategy described in the *Task/Site Work Plan for Operable Unit 1049: Los Alamos Canyon and Pueblo Canyon* ("the work plan") (LANL 1995, 50290; LANL 1997, 56421) and modified by the *Core Document for Canyons Investigations* ("the core document") (LANL 1997, 55622; LANL 1998, 57666). Data collected from these reaches are used to define the nature and extent of contamination within young alluvial sediments (post-1942 sediments), to revise a conceptual model for contaminant distribution and transport, to perform screening assessments for potential human and ecological risk, and to determine if there is a need for immediate remedial action or additional data collection. In a future report these data will be combined with additional data on sediment, groundwater, and surface water in Los Alamos Canyon and Pueblo Canyon to support a canyons-wide assessment, which will involve a more comprehensive assessment of human and ecological risk related to present-day levels of contamination and the effects of future transport of contaminants.

1.2 Regulatory Context

Regulatory requirements governing the ER Project canyons investigations are discussed in Section 1.4 of the core document (LANL 1997, 55622). In particular these investigations address requirements of Module VIII of the Laboratory's Hazardous Waste Facility Permit ("the HSWA Module") (EPA 1990, 1585) under the Resource Conservation and Recovery Act (RCRA), including addressing "the existence of contamination and the potential for movement or transport to or within Canyon watersheds." In addition to federal and state regulations, Department of Energy (DOE) Order 5400.5, "Radiation Protection Of The Public And The Environment," provides guidance on residual radioactivity at DOE facilities.

1.3 Background

1.3.1 Geography, Geology, and Hydrology

Pueblo Canyon heads on the flanks of the Sierra de los Valles on Santa Fe National Forest land. It extends across land owned by Los Alamos County and crosses the northeast corner of the Laboratory to its confluence with Los Alamos Canyon. Pueblo Canyon has a drainage area of 21.7 km^2 and a basin length of approximately 16 km. Geologic units exposed within the Pueblo Canyon watershed include Pliocene and Miocene dacites of the Tschicoma Formation, Pliocene conglomerates of the Puye Formation, Quaternary ignimbrites of the Otowi and Tshirege Members of the Bandelier Tuff, and Quaternary pumice beds and volcaniclastic sediments of the Cerro Toledo interval (Griggs 1964, 8795; Smith et al. 1970, 9752).

Stream flow in Pueblo Canyon has included both ephemeral runoff from rain storms and snowmelt and extended discharges of treated effluent from three different wastewater treatment plants. The westernmost plant was the Pueblo Canyon Wastewater Treatment Plant (WWTP) upstream of Acid Canyon, which operated from 1951 until 1991. The Central WWTP was located farther east on the south rim of Pueblo Canyon and operated from 1947 until 1966. The Bayo Canyon WWTP, located between lower Pueblo Canyon and Bayo Canyon, began operating in 1963 and is the active sewage treatment plant for the town of Los Alamos, producing frequent flow in lower Pueblo Canyon. Although storm runoff provides the largest stream flows and the highest potential for erosion and sediment transport in Pueblo Canyon, the effluent discharge has provided longer periods of lower flow that may have been particularly effective at maintaining high water tables and allowing denser vegetation to become established and also providing more opportunity for subsurface transport of contaminants.

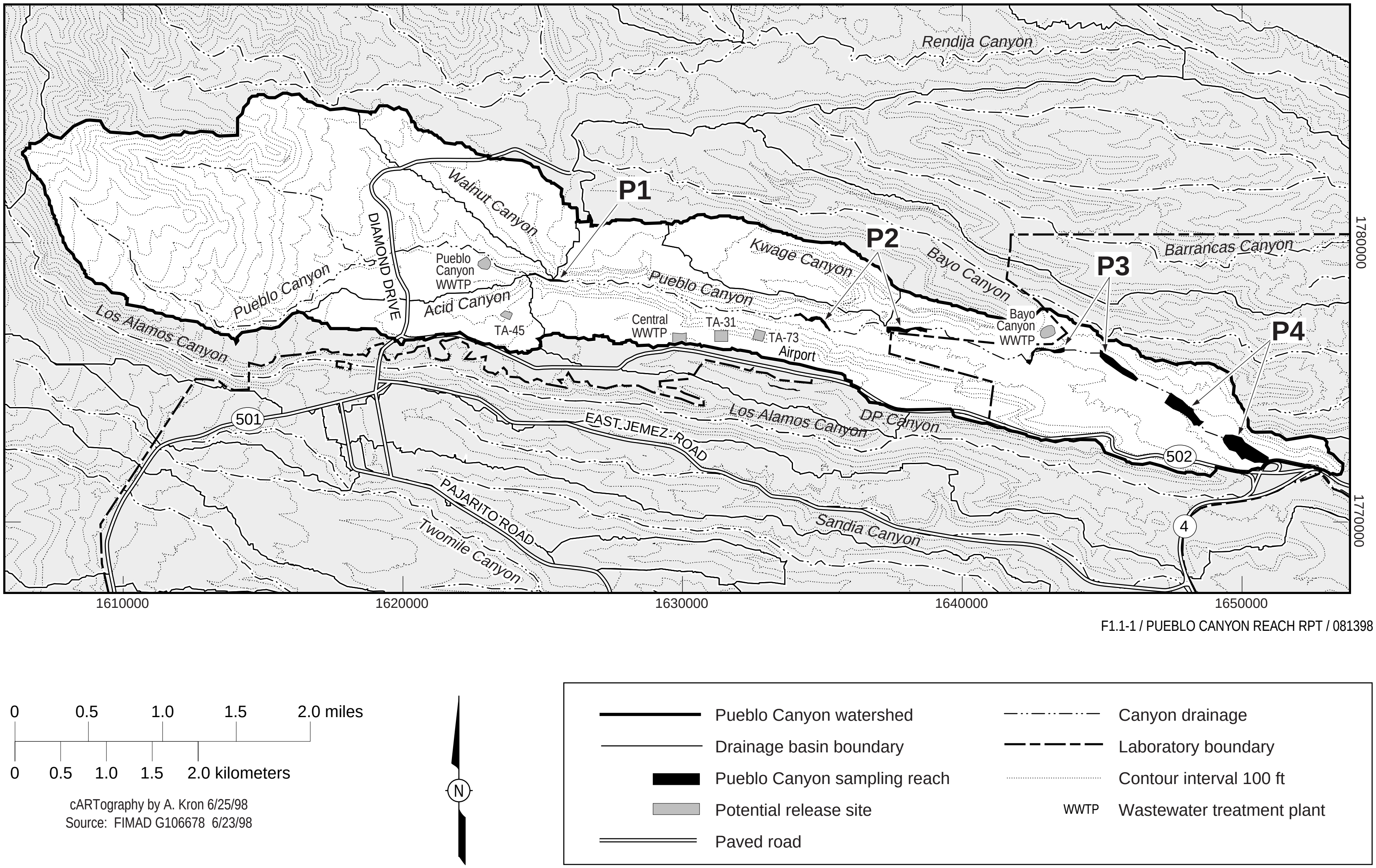

Figure 1.1-1. Pueblo Canyon watershed.

1.3.2 Laboratory History and Operations

Several former Laboratory sites within the Pueblo Canyon watershed have or may have contributed contaminants to the main channel of Pueblo Canyon, including some of the original Manhattan Project facilities within the current Los Alamos townsite that date back to 1943. Treated and untreated radioactive liquid waste derived from many separate facilities was discharged from former Technical Area (TA) -45 into Acid Canyon, a small tributary to Pueblo Canyon (Figure 1.1-1), constituting the principal source of contamination in the watershed. Liquid releases from septic tank outfalls and from municipal wastewater treatment plants constitute additional potential sources of Laboratory-derived contaminants for the main channel; surface runoff from contaminated sites also may have contributed some contaminants. Brief summaries of pertinent information on key sites in the Pueblo Canyon watershed are presented below.

The principal source of contamination in Pueblo Canyon was TA-45 (Figure 1.1-1), site of the first radioactive liquid waste treatment facility at the Laboratory (Potential Release Site [PRS] 45-001) (LANL 1981, 6059; LANL 1992, 7668). Effluent from TA-45 released into Acid Canyon included untreated liquid waste from 1944 to 1951 and treated liquid waste from 1951 to 1964. Radionuclides detected above background values downstream from the outfalls (PRSs 1-002 and 45-004) in sediment samples collected during ER Project investigations include americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90; uranium-234; uranium-235; and uranium-238. Americium-241; cesium-137; and plutonium-239,240 locally exceeded screening action levels (SALs) (LANL 1996, 54468). In addition lead, mercury, and silver were detected above background values but below SALs (LANL 1995, 48856). Demolition of structures at TA-45 and excavation of contaminated soils occurred in 1966 before the land was released to Los Alamos County in 1967; additional remediation occurred in 1982.

Additional releases into Acid Canyon occurred from the outfall of a septic tank that was installed in the 1940s (PRS 0-030[g]). Plutonium-239,240 and polychlorinated biphenyls (PCBs) above SALs were found below the outfall during ER Project investigations (LANL 1995, 51983).

Pueblo Canyon may also have received contaminants from operations at former TA-31 and TA-73 near the Los Alamos Airport, although this is not certain. TA-31 was known as the east receiving yard, and PCBs at levels above SALs were found at the mouth of a former septic tank outfall pipe (PRS 31-001) (LANL 1995, 57050). Operations at TA-73 included incinerating classified documents and disposing of various types of waste; steam-cleaning garbage cans, trucks, and dumpsters; operating a landfill and burning municipal and laboratory waste; disposing of waste oil; storing high explosives (HE); operating a surface disposal facility; and operating an asphalt batch plant (LANL 1992, 7667). Outfalls, drainlines, and septic systems were associated with a number of former operations at TA-73. An ash pile from the former incinerator (PRS 73-002) contains several analytes above SALs (antimony, barium, cadmium, copper, lead, silver, thallium, and PCBs) (LANL 1997, 56606), and surface runoff from this site may provide an additional source of contaminants for Pueblo Canyon.

Effluent from the three municipal wastewater treatment plants in the watershed could potentially provide Laboratory-derived contaminants to Pueblo Canyon, although contaminants from these plants could also have non-Laboratory sources. In particular, sludge from the Pueblo Canyon WWTP upstream of Acid Canyon (PRS 0-018[a]) contains a series of analytes above background values (barium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, zinc, and uranium-235), although none of these are above SALs (LANL 1997, 56614).

1.4 Current Land Use

Pueblo Canyon downstream from Acid Canyon includes land owned by Los Alamos County and the DOE, all of which is open to the public. Present land use includes various recreational activities such as hiking and bicycle riding. There is good trail access into Pueblo Canyon near Acid Canyon from nearby residential areas in Los Alamos, and trails and dirt roads continue down the length of the canyon (Kron 1993, 58665). Sewer lines from the Los Alamos townsite are buried beneath the narrow canyon floor for 4 km downstream from Acid Canyon. The lower canyon is used as a discharge site for treated effluent from the Bayo Canyon WWTP. In the Los Alamos County comprehensive plan, the county-owned part of Pueblo Canyon, which includes the confluence with Acid Canyon, has been designated as “scenic open space” since 1964 (Los Alamos Planning Commission 1964, 56873). The part of Pueblo Canyon on DOE land (TA-74), extending upstream from the confluence with Los Alamos Canyon, is presently being considered for potential land transfer to either Los Alamos County or San Ildefonso Pueblo (DOE 1998, 58671)**.**

1.5 Previous Sediment Investigations

Contaminants associated with sediments in Pueblo Canyon have been investigated in many studies since the initial contaminant releases from TA-45. The first sediment sampling, in 1946, indicated the presence of plutonium along the full length of Pueblo Canyon downstream from Acid Canyon, documenting rapid transport along a distance of 11 km from the source (Kingsley 1947, 4186). Subsequent work has included repeated sediment sampling at a series of stations as part of the Laboratory Environmental Surveillance Program since 1970 (e.g., Environmental Surveillance and Compliance Programs 1997, 56684) and more intensive studies in the 1970s. Work in the 1970s included studies by the Laboratory Environmental Sciences Group (e.g., Hakonson and Bostick 1975, 29678; Nyhan et al. 1976, 11747; Nyhan et al. 1982, 7164) and investigations under the Formerly Utilized Sites Remedial Action Program (FUSRAP) (LANL 1981, 6059). More recently, existing data on plutonium in sediments were combined with geomorphic mapping of Pueblo Canyon to provide an improved estimate of the inventory of plutonium in the canyon (Graf 1995, 48851; Graf 1996, 55537). Some of this earlier work is summarized in the work plan (LANL 1995, 50290) and formed the basis for a preliminary conceptual model of contaminant distribution and transport and for design of a technical approach for the present investigations, as summarized in the next section.

1.6 Preliminary Conceptual Model and Technical Approach

Available data on contaminants in Pueblo Canyon sediments prior to this investigation indicated that plutonium-239,240 discharged into Acid Canyon from TA-45 is the primary contaminant of concern, although some other radionuclides and metals have also been reported above background values. Because of its geochemical characteristics, nearly all the plutonium was adsorbed onto sediment particles, and subsequent transport of plutonium has been largely controlled by sediment transport processes. Other contaminants released from TA-45 are expected to behave similarly and to be collocated with the plutonium. These contaminants have been dispersed by floods along the 10-km section of Pueblo Canyon downstream from Acid Canyon since initial development of the Laboratory in 1943. Contaminant concentrations in post-1942 sediments vary greatly, related to factors such as the distance from the source, sediment particle size, and the age of the deposit. Plutonium concentrations are expected to be generally higher in sediment deposits closer to the source and in finer-grained sediments than in downstream deposits or in coarser-grained sediments. In addition, plutonium concentrations are expected to be highest in sediment deposits that are relatively close to the age of the peak contaminant releases and lower in younger sediments. The greatest portion of the total plutonium inventory in Pueblo

Canyon is believed to occur in the lower several kilometers of the canyon where large amounts of sediment have been deposited by floods since 1943 (LANL 1981, 6059; LANL 1995, 50290; Graf 1996, 55537).

The technical approach adopted in this investigation includes detailed geomorphic mapping and sediment sampling in a series of reaches selected at key locations in the canyon, following the “representative reach” concept presented by Graf (1994, 55536). This work was focused on determining the nature and extent of contamination, evaluating risk, and testing components of the preliminary conceptual model in a phased approach. Geomorphic mapping and sediment sampling concentrated on identifying and characterizing post-1942 sediments, those sediments younger than the initial contaminant releases. An evaluation of data collected in each phase was used to revise the conceptual model, identify key uncertainties, and focus subsequent data collection. Investigation goals include evaluating present and future potential risk, evaluating sediment transport processes and future contaminant redistribution, and providing data necessary to make decisions about possible remedial action alternatives.

1.7 Deviations from the Work Plan

While conducting the sediment investigations in Pueblo Canyon, the Canyons Focus Area technical team made some modifications to the proposed work described in Section 7.2 of the work plan (LANL 1995, 50290). These deviations are briefly discussed below.

Because of considerable geomorphic complexity identified in Pueblo Canyon after field work was initiated, geomorphic mapping and sediment sampling were conducted in several additional areas not specified in the work plan, which increased the total area of investigation. The areas not proposed in the work plan, which were designated as subreaches, consist of the following areas. Reach P-2 East is an area where considerable widening of the active channel occurs downstream from a tributary drainage (“Kwage Canyon”); the original reach P-2 was redesignated P-2 West. Reach P-3 West is an area extending immediately upstream from the Bayo Canyon WWTP outfall and which was easier to investigate than downstream areas with a high water table; the original reach P-3 was redesignated P-3 East. Reach P-4 West is an area where abandoned post-1942 channel units attain their greatest width in Pueblo Canyon and where large sediment deposits were produced in the 1950s to 1960s; the original reach P-4 was redesignated P-4 East.

Radiological field surveys conducted in reaches P-1 and P-4 in 1996 revealed that the concentrations of radionuclide contaminants were generally too low to allow definition of the extent of contaminated sediments using field instruments. The only exception was in P-1 where plutonium concentrations in some places were high enough to allow detection of associated alpha radiation. Because of these findings, no radiological surveys were conducted in reaches P-2 and P-3, and sample site selection there was based entirely on geomorphic criteria instead of relying on field radiological data as was proposed in the work plan. Analytical data on samples collected from P-2 and P-3 in 1997 confirmed that plutonium activities were too low to allow effective use of radiological field instruments in these reaches.

The criteria for selecting specific sampling intervals for limited-suite analyses and the number of such analyses in each reach were modified from those proposed in the work plan based on the results of the full-suite analyses. In particular, the full-suite analyses indicated that radionuclides and metals identified above background values were collocated with plutonium in both upstream and downstream reaches, and the technical team decided to focus limited-suite samples on testing the validity of this apparent collocation. The number of samples in each unit in each reach was decided to be less important for the purposes of statistical evaluation than the total number of samples in the canyon as long as there was good spatial coverage and the samples analyzed for the limited suite included the full range of sediment ages, particle size characteristics, and plutonium concentration. Consequently, although the work plan specified collecting at least 12 limited-suite samples in each reach, only 8 each were collected in P-2 and P-3. Sample sites were selected to include both coarse-grained channel facies sediment and fine-grained overbank facies sediment from geomorphic units with a range of ages. In addition, the specific sample intervals that yielded the highest plutonium concentrations in each reach during the initial sampling events were resampled for limited-suite analyses in subsequent sampling events.

Sample preparation deviated from that specified in the work plan by the decision to sieve each sample to remove all gravel and organic matter larger than 2 mm before analysis. The work plan had specified removal by hand of large stones and organic and other debris, but the technical team decided later that this process would not provide enough consistency in sample preparation.

1.8 Unit Conventions

This report uses primarily metric units of measure, although English units are used for contours on topographic maps, in reference to elevations derived from topographic maps, and for New Mexico State Plane coordinates as shown on some maps. English units are also used for radioactivity (curies [Ci] instead of becquerels [Bq]). Scales with both metric and English units of distance are shown on maps. Conversions from metric to English units are presented in Appendix A-2.0.

1.9 Report Organization

Section 2 of this report presents results of the field investigations of sediments in the Pueblo Canyon reaches. Section 2.1 introduces each reach and its major geographic characteristics. Section 2.2 describes the methods of investigation in the reaches, including geomorphic mapping, physical characterization of young sediments, radiological field measurements, and sediment sampling activities. Section 2.3 presents results of these field investigations in each reach, including physical and radiological characteristics of the geomorphic units and key aspects of the post-1942 geomorphic history.

Section 3 of this report presents analytical results from sediment samples collected in the Pueblo Canyon reaches. Section 3.1 is a data review that evaluates which radionuclides and organic and inorganic chemicals should be retained as chemicals of potential concern (COPCs). Section 3.2 evaluates each COPC in the context of likely sources within the Pueblo Canyon watershed and possible collocation with other COPCs. Section 3.3 presents a detailed evaluation of plutonium data from sediment samples collected in each reach, focused on plutonium-239,240, which was selected as a key contaminant in this investigation. Included in Section 3.3 are discussions of variations in plutonium concentration among the different geomorphic units in each reach, the relations of plutonium concentration to the age and particle size characteristics of the sediment deposits, the amount (inventory) of plutonium contained within the different units, and the potential for remobilization of plutonium contained within the different units.

Section 4 of this report presents a conceptual model describing contamination in the sediments of Pueblo Canyon, which has been revised and refined from the preliminary conceptual model presented in the work plan based on the results of this investigation. Section 4.1 discusses the present nature and extent of contamination in Pueblo Canyon sediments. Section 4.2 discusses controls on contaminant distribution, including the effects of particle size variations on plutonium concentration and temporal and spatial trends in plutonium concentration. Section 4.3 discusses the fate and transport of contaminants in the sediments of Pueblo Canyon, including processes that have redistributed contaminants since the initial releases and future remobilization and transport of these contaminants.

Section 5 of this report presents preliminary assessments of potential human and ecological risk related to contaminants contained within the sediments of Pueblo Canyon. Section 5.1 presents the human health risk assessment. Section 5.2 presents the ecological screening assessment.

Section 6 of this report summarizes key conclusions of this investigation, highlights key remaining uncertainties, and provides recommendations concerning possible additional assessments, data collection, and/or remedial action.

Section 7 presents references cited in this report.

Appendix A presents a list of acronyms used in this report, metric to English conversions, and metric prefixes.

Appendix B presents supplemental information on the characterization of geomorphic units in the Pueblo Canyon reaches. Appendix B-1.0 presents dendrochronological analyses (tree-ring dating). Appendix B-2.0 presents data on the thickness of post-1942 fine-grained overbank facies sediment in the different geomorphic units. Appendix B-3.0 presents data on particle size characteristics and organic matter content in the sediment samples. Appendix B-4.0 presents bulk density measurements. Appendix B-5.0 presents radiological field measurements in reaches P-1 and P-4, including discussion of instrument calibration and use. Appendix B-6.0 presents the chronology of sediment sampling events in the Pueblo Canyon reaches and the primary goals of each sampling event.

Appendix C presents the results of quality assurance (QA) and quality control (QC) activities pertaining to the Pueblo Canyon sediment samples. Appendix C-1.0 summarizes the QA/QC activities. Appendix C-2.0 addresses inorganic chemical analyses. Appendix C-3.0 addresses radiochemical analyses. Appendix C-4.0 addresses organic chemical analyses. Appendix C-5.0 presents data qualifiers for the samples.

Appendix D presents analytical suites and results of sediment analyses in this investigation. Appendix D-1.0 presents target analytes and detection limits. Appendix D-2.0 presents sample request numbers and analytical suites for each sample. Appendix D-3.0 presents summaries of analytical results. Appendix D-4.0 presents analytical results for COPCs.

Appendix E presents supplemental statistical analyses of the analytical results of this investigation. Appendix E-1.0 presents statistical evaluations of the inorganic chemical data. Appendix E-2.0 presents statistical evaluations of the radionuclide data. Appendix E-3.0 evaluates the possible collocation of COPCs. Appendix E-4.0 presents an analysis of plutonium-239,240 field QA samples and resampled layers.

Appendix F-1.0 presents the ecological scoping checklist for the Pueblo Canyon reaches.

1.10 Acknowledgments

The authors of this report had the following responsibilities. Reneau was responsible for documenting the field investigations and interpreting the analytical results in the context of the field setting and was also the principal investigator for sediment characterization during the field work. Ryti was responsible for data review, statistical analyses, and ecological screening and was also the lead for statistical analysis during all phases of the field investigation. Tardiff was responsible for the human health risk assessment included in this report. Linn was responsible for the data validation activities included in this report.

In addition to the authors of this report, numerous individuals contributed to this investigation.

Paul Drakos, Danny Katzman, Eric McDonald, and Brad Wilcox contributed to the geomorphic characterization activities. Wilcox contributed to development of the original technical strategy in the work plan and to initial phases of the field investigation. McDonald contributed to initial phases of the field investigations; helped develop field criteria for recognizing buried soils and the thickness of post-1942 sediment deposits; performed bulk density measurements; and was the lead for particle size analysis and development of a sediment background data set. Drakos and Katzman contributed to the second year of the field investigations, and Drakos was the lead for dendrochronological analyses.

Linnea Wahl lead the radiological field screening activities and provided summaries of these activities. Gross gamma radiation walkover surveys were performed by the Environmental Restoration Group (ERG) (Dave Hunter, Darrio Rocha, and John Taylor) and Chemrad (Mike Blair, Chuck Flynn, and Brett Lawrence), and fixed-point radiological measurements were performed by ERG and by ERM under the direction of Wahl. Florie Caporuscio lead initial planning for the radiological screening activities.

Johnnye Lewis was the lead for risk assessment during the field investigations. Ralph Perona contributed to risk assessment activities during both the field investigations and report preparation. Alison Dorries was the lead for initial development of the risk assessment approach in the work plan.

Jeff Blossom, Marcia Jones, and Matt Rice provided geographic information system (GIS) support. Jenny Harris was the lead for sediment sampling. Deba Daymon was the field team manager. Data management support was provided by Felicia Aguilar, Candi Chroninger, and Robert Trujillo. Ken Mullen provided environmental surveillance data. Maureen Oakes served as editor for this report; Christy Fläming was the graphic artist, and Pam Maestas was the compositor. Assistance in this investigation was also provided by the following individuals, including help with field work, data analysis, and report preparation: Larry Baker, Andy Crowder, Clint Daymon, Dave Frank, Rose Gallaway, John Hayes, Mike Henke, Lorrie Houston, Andi Kron, Jared Lyman, Mary Mullen, Trung Nguyen, Marty Peifer, Stephanie Pratt, Carmella Romero, Celina Salazar, Jim Santo, Cathy Smith, Darrill Stafford, Jeff Walterscheid, and Ray Wright.

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Finally, Will Graf provided early technical inspiration for part of the approach to geomorphic characterization used in this investigation; Dave Broxton provided guidance as the technical team leader throughout work plan preparation, field work, and report preparation; and Allyn Pratt supported all phases of this investigation as leader of Field Unit 4 and the Canyons Focus Area.

2.0 FIELD INVESTIGATIONS

2.1 Introduction to Reaches

The initial locations of the Pueblo Canyon reaches were selected to address a variety of goals, including identifying variations in contaminant concentration, contaminant inventory, and risk along the length of Pueblo Canyon and improving the understanding of transport processes (LANL 1995, 50290). Each reach was intended to be long enough to capture local variations in contaminant concentrations related to variations in the age, thickness, and particle size of young (post-1942) sediment deposits but short enough that the effects of downstream dilution of contaminants were minimized. During field work, the geographic boundaries of the reaches were finalized, including the addition of subreaches to better define geographic variations in contamination. The location of the reaches within the Pueblo Canyon watershed is shown in Figure 1.1-1, and topographic maps of the individual reaches, showing simplified geomorphic maps, are shown in Figures 2.1-1 to 2.1-4. The general nomenclature for the geomorphic units shown on the maps is discussed in Section 2.2.1.1, and the specific units in each reach are discussed in Section 2.3. Geographic characteristics of these reaches are briefly summarized below.

Reach P-1 includes the confluence of Acid Canyon and Pueblo Canyon; it is the area where contaminant concentrations were expected to be highest because of the proximity to TA-45, which is the primary source of contaminants in the watershed. Walnut Canyon, a major tributary that drains part of the Los Alamos townsite, also joins Pueblo Canyon in this reach. The canyon floor here is relatively steep, narrow, and rocky. The stream is incised into the Tshirege Member of the Bandelier Tuff near Acid Canyon, into Tschicoma Formation dacite west of Walnut Canyon, and into the Otowi Member of the Bandelier Tuff farther east. P-1 West is a short subreach upstream of Acid Canyon, and P-1 East is a relatively long subreach that extends downstream from the confluence.

Reach P-2 is an area downstream of P-1 where the channel becomes less steep and the canyon floor begins to broaden in the Otowi Member of the Bandelier Tuff, enhancing the opportunity for sediment deposition. This is also the westernmost area in Pueblo Canyon where stream terraces that may be suitable for residential development occur above the active floodplain. A tributary canyon between North Mesa and Kwage Mesa, referred to as Kwage Canyon in this report, enters Pueblo Canyon in this reach and is associated with a major increase in channel width. The change in channel characteristics downstream from Kwage Canyon suggests that this canyon is a significant sediment source. P-2 West is the narrower area upstream from Kwage Canyon, which includes the site of test wells TW-2 and TW-2A, and P-2 East is the broader area downstream from Kwage Canyon. P-2 East includes the part of Pueblo Canyon with the lowest stream gradient.

Reach P-3 includes the area of the Bayo Canyon Wastewater Treatment Plant (WWTP), and the stream channel here becomes slightly steeper than upstream as it begins incising into conglomerates of the Puye Formation. The canyon floor is fairly broad through this area. P-3 West is upstream from the WWTP outfall and includes Hamilton Bend. P-3 East is downstream from the outfall and has continuous surface flow and a high water table during most of the year.

Reach P-4, which includes the lowest part of Pueblo Canyon, is a geomorphically complex area where the channel elevation has varied greatly since 1942 because of the deposition of large amounts of sediment and subsequent channel incision (Reneau and McDonald 1996, 55538; Reneau et al. 1996, 57642). P-4 West includes large sediment deposits from the early post-1942 period and has a deeply incised channel. P-4 East has large sediment deposits from later in the post-1942 period, which have also been incised. P-4 East also has an exceptionally broad post-1942 floodplain, larger than in any other part of Pueblo Canyon. The channel is steeper in P-4 than immediately upstream, and the channel is incised into the Puye Formation.

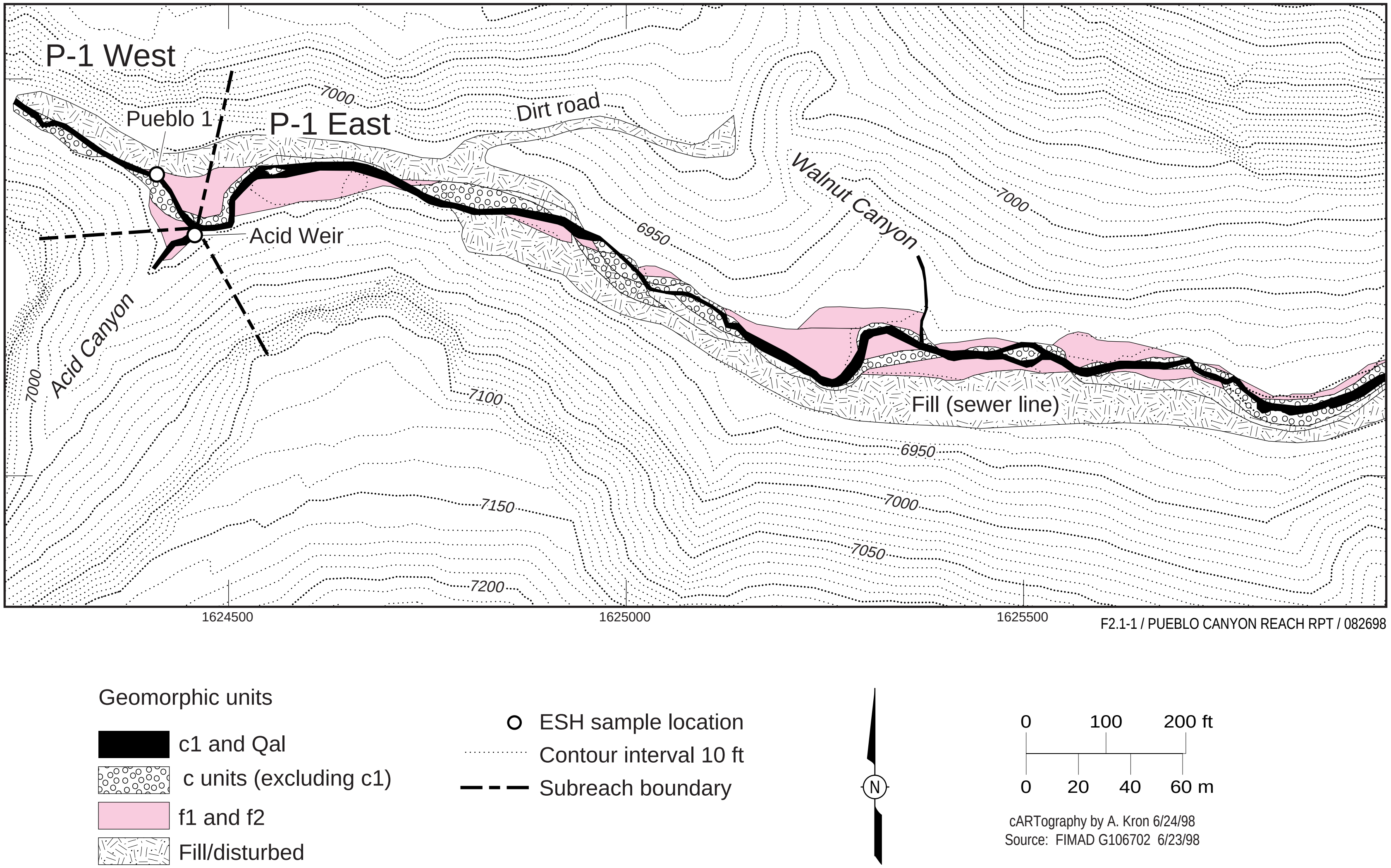


Figure 2.1-1. Topographic map of reach P-1 showing generalized geomorphic units.

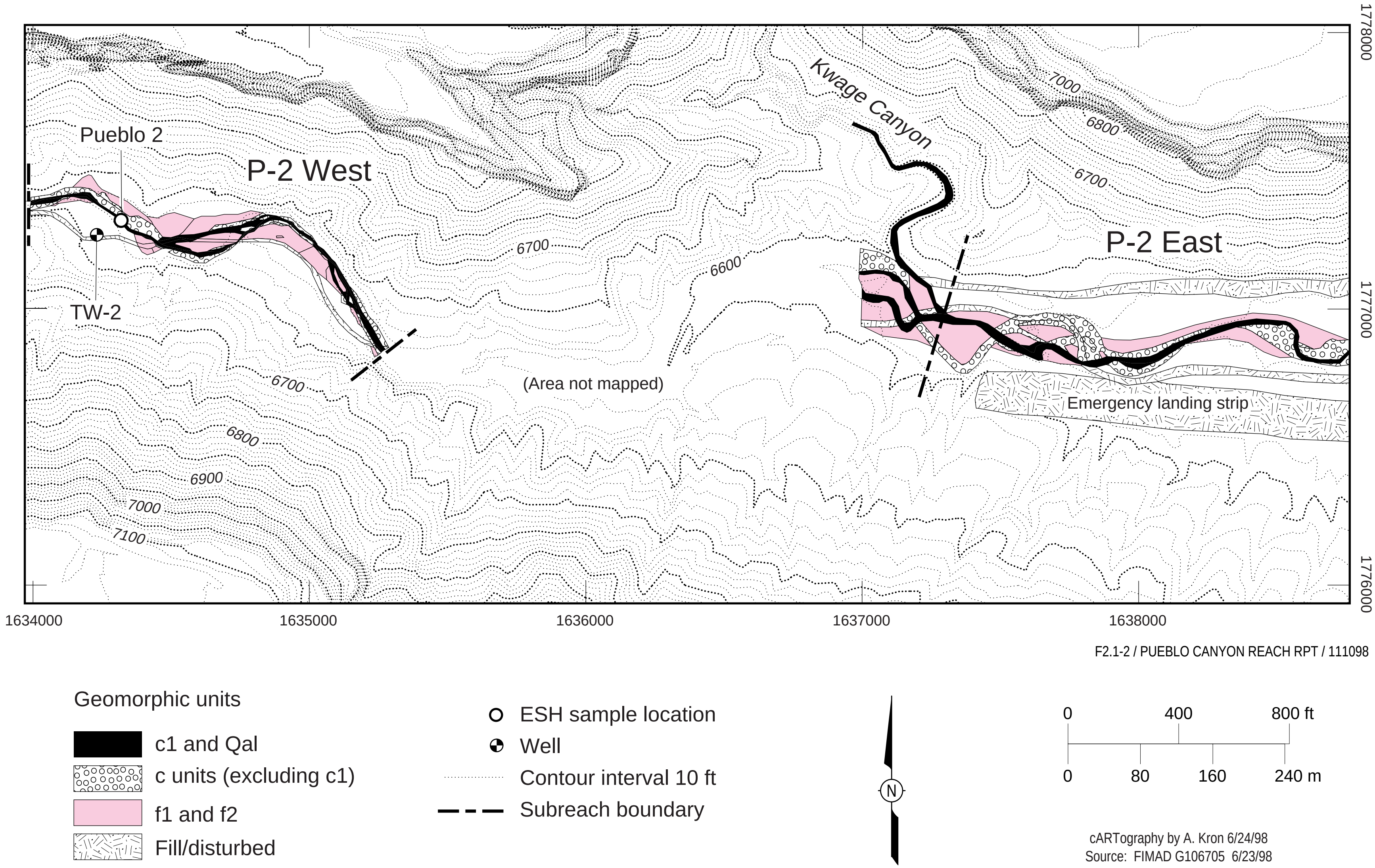


Figure 2.1-2. Topographic map of reach P-2 showing generalized geomorphic units.

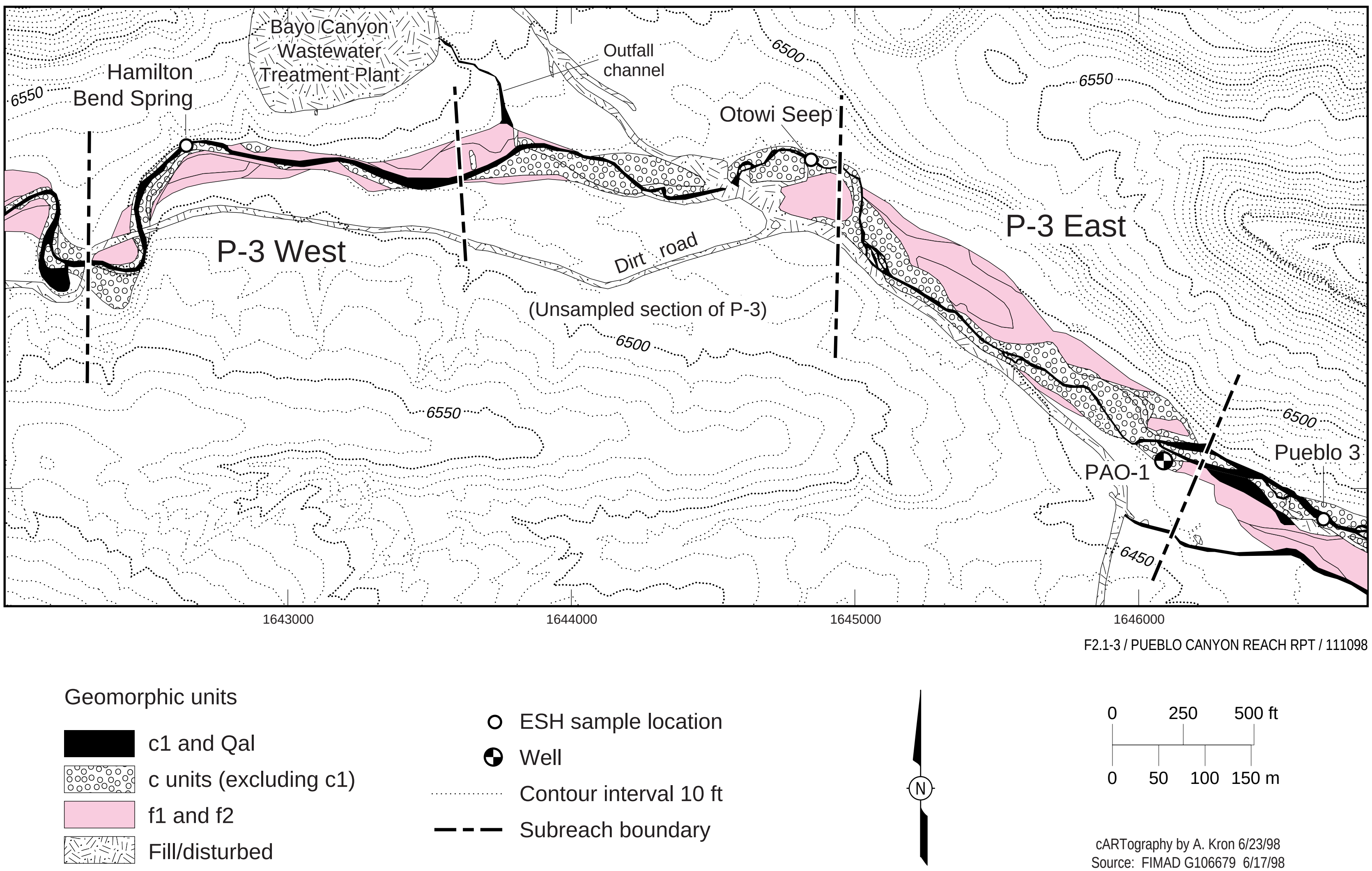


Figure 2.1-3. Topographic map of reach P-3 showing generalized geomorphic units.

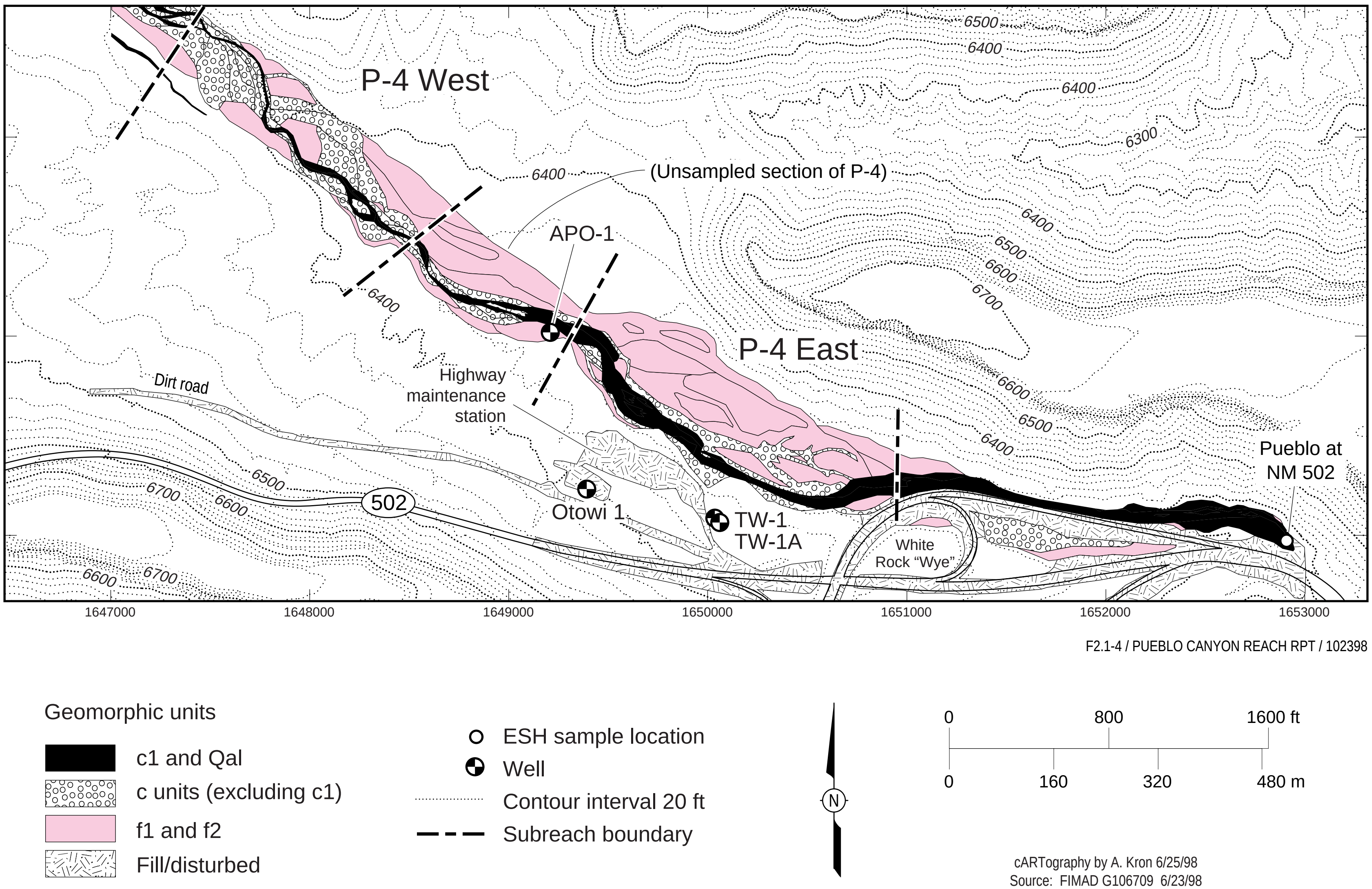


Figure 2.1-4. Topographic map of reach P-4 showing generalized geomorphic units.

2.2 Methods of Investigation

2.2.1 Geomorphic Mapping

Field investigations in each reach began by preparing a preliminary geomorphic map that focused on identifying young (post-1942), potentially contaminated sediment deposits and subdividing these deposits into geomorphic units with different age, sedimentological characteristics, and/or radiological characteristics. These geomorphic units delineate the horizontal extent of contamination in each reach and also provide grouping of areas with similar physical and/or radiological characteristics. Where uncertainties existed in identifying the limits of potentially contaminated sediments, boundaries were drawn conservatively such that the area potentially impacted by post-1942 floods was overestimated rather than underestimated.

The scale and methods of mapping varied dependent on the characteristics of the reach. In broad, open areas to the east (particularly reaches P-4 and P-3 East), mapping at a scale of 1:1200 used high-resolution 1991 orthophotographs, which allowed relatively precise mapping of boundaries between geomorphic units. The approximate ages of many sediment deposits in these areas could also be determined by examining sequential aerial photographs that date back to 1935; these photographs in turn allowed refinement of the boundaries between units of different age. In the narrow canyon floor to the west (particularly P-1), tree cover obscured the canyon floor, and the smaller size of geomorphic units required mapping at a larger scale. Mapping in P-1 was at a scale of 1:200 and involved taping distances along the channel from known reference points and frequently measuring unit width. Mapping in P-2 and P-3 West used a combination of these methods. Boundaries between geomorphic units were typically defined on the basis of topographic breaks, vegetation changes, and/or changes in surface sediments, although in some areas boundaries are more approximate.

Geomorphic mapping was iterative, and the maps were revised after each phase of investigation in each reach. For example, in P-1 field radiological measurements and laboratory analytical data were used to define a relatively small area with elevated plutonium concentrations, which was broken out as a separate geomorphic unit (unit c2b). In addition, geodetic surveying of sample locations that followed each sampling event often led to map revisions so that the surveyed sample locations were within the appropriate geomorphic unit. Refining of the conceptual model during the investigations also resulted in reexamination of previous map assignments and additional revisions to the maps.

2.2.1.1 Geomorphic Unit Nomenclature

The nomenclature used for geomorphic units is consistent among reaches and subreaches where possible, although complete consistency was not possible. The following general convention was used for naming units.

The designation “c” refers to post-1942 channel units, which are areas occupied by the main stream channel or experiencing significant deposition of coarse-grained channel sediments sometime in the post-1942 period. “c1” is the presently active channel, “c2” is the youngest recognized abandoned channel unit in each reach, and so on. Letter modifiers (e.g., “c2a”) are further subdivisions, with “a” being youngest. Available data did not allow each named unit to be the same age in every reach. For example, the “c2” unit in P-4 delineates areas occupied by the channel during the 1980s but abandoned before 1991, as shown by examination of sequential aerial photographs. However, such precise age constraint was not possible in most reaches, and “c2” in other reaches includes a longer and more poorly defined period of time.

The designation “f1” refers to floodplain areas that were or may have been inundated by overbank floodwaters since 1942, but that were not occupied by the main stream channel. “f1” indicates areas that were probably inundated by floods during this period, as shown by geomorphic evidence and/or analytical data. “f2” indicates areas that were possibly subjected to minor inundation but where the evidence is inconclusive; if they were inundated, the thickness of post-1942 sediment would be small. The designation “f1a” is used in P-4 West to indicate a floodplain area where plutonium is above background, but which is dominated by sediment from a tributary drainage, such that the average plutonium concentration is relatively low.

Other designations on the geomorphic maps delineate various areas that have not been directly impacted by post-1942 floods downstream of potential contaminant sources. Following standard geologic nomenclature, “Q” indicates deposits from the Quaternary period. “Qal” refers to active channel alluvium in tributary drainages. “Qc” refers to colluvium. “Qt” refers to pre-1943 stream terraces that have not been inundated by post-1942 floods. “Qf” refers to fans from tributary drainages. Sometimes bedrock geologic units are also shown on these maps.

2.2.2 Physical Characterization of Young Sediments

Physical characterization of the geomorphic units included measurements of the thickness of post-1942 sediments, general field descriptions of particle size, and laboratory particle size analysis for samples submitted for standard chemical and/or radiological analyses. Bulk density was also measured on a subset of sample intervals for use in calculating contaminant inventories. The determination of unit thicknesses used a variety of approaches, including identifying the depth of burial of trees; recognizing buried soil horizons; and searching for the presence of “exotic” material that indicates a post-1942 age (e.g., quartzite clasts, coal, or various man-made materials). Plutonium analyses were also used at some sites to directly determine the thickness of contaminated sediment and provide supporting evidence for the inferred thickness of post-1942 sediment, although in some areas plutonium may extend into pre-1943 sediment because of vertical translocation, particularly below active channels. Selected trees were cored for dendrochronologic analysis (tree-ring dating) to help confirm the thickness of post-1942 sediment and to provide improved age estimates for specific sediment deposits (see Stokes and Smiley 1968, 57644, for a discussion of tree-ring dating methods). Additional details of the methods and results of the physical characterization of post-1942 sediment in the Pueblo Canyon reaches are presented in Appendix B.

An important distinction within the post-1942 sediments involves general particle size variations because contaminant concentrations tend to be higher in finer-grained sediments of a given age. Field measurements focused on differentiating “overbank facies” and “channel facies” sediments, which are similar to the “top stratum” and “bottom stratum” of Brakenridge (1988, 57640). As used in this report, “overbank facies” refers to sediment generally transported as suspended load during floods, which are commonly deposited on floodplains from water that overtops stream banks, and “channel facies” refers to sediment generally transported as bed load and deposited along the main stream channel. Overbank facies sediment has typical median particle size of silt to fine sand, and channel facies sediment has typical median particle size of coarse or very coarse sand; medium sands could be assigned to either facies, depending on the stratigraphic context. These facies are not restricted to specific geomorphic units; overbank facies sediment typically forms upper layers on floodplains and abandoned channel units and can also be found as thin layers along active channels, and channel facies sediment can be deposited on floodplains during large floods and associated with channel aggradation. It should also be stressed that these distinctions are somewhat arbitrary, with gradations commonly occurring. Nevertheless, they form an important basis for differentiating sediment deposits of similar age that may have much different levels of contamination.

2.2.3 Radiological Field Measurements

The initial geomorphic mapping in reaches P-1 and P-4 was followed by use of a series of field instruments to define differences in alpha, beta, and gamma radiation between the geomorphic units and to focus subsequent sampling. Extensive low-resolution gross gamma radiation walkover surveys were followed by higher resolution “fixed-point” alpha, beta, and gamma radiation measurements at selected field locations; a subset of these fixed-point locations was selected for *in situ* gamma spectroscopy measurements. These measurements were made during a pilot study phase of investigation when the utility of different field methods was being evaluated. Because of the relatively low concentrations of radiological contaminants in these reaches, most methods were not found to be useful in delineating contamination in Pueblo Canyon sediments, with the exception of fixed-point alpha measurements in P-1. Because of this, only the fixed-point alpha measurements are discussed in the body of this report, although methods and results from all the field instruments are presented in Appendix B-5.0

2.2.4 Sediment Sampling and Preliminary Data Evaluation

Sediment sampling in this investigation followed a phased approach that included a combination of sampling for “full-suite,” “limited-suite,” and “key contaminant” analyses. Preliminary evaluation of data after each sampling phase was performed to help identify uncertainties and to focus subsequent sample collection and analysis. The primary goals and other information about each sampling event are summarized in Appendix B-6.0

Full-suite analyses were obtained on samples from P-1 and P-4 after the field radiological surveys, with the goal of identifying all analytes that were present above background values and determining the primary risk drivers. The specific sample sites and sample depths included intervals with the highest field radiological measurements in each reach as well as intervals with relatively low radiation. The sample sites also included representative fine-grained and coarse-grained sediment deposits from the range of geomorphic units. The full-suite analyses included a series of inorganic chemicals, organic chemicals, and radionuclides and are listed in Section 3.1 and Appendix C.

Subsequent sampling phases in all reaches were primarily for a single key contaminant, plutonium, because plutonium-239,240 (unresolved isotopes) was shown by prior sediment investigations (LANL 1981, 6059; Ferenbaugh et al. 1994, 58672) and by the full-suite analyses to be the main risk driver; data on plutonium-238 were also obtained during these analyses. (For brevity, “plutonium” in this section will be used synonymously with plutonium-239,240 because of the relatively low levels of plutonium-238 in Pueblo Canyon sediments.) Specific sample sites in each sampling event were selected to reduce uncertainties in the horizontal and vertical extent of contamination, the average and range of plutonium concentrations in each unit, the inventory of plutonium, and controls on its distribution (e.g., effects of sediment age and sediment particle size).

To most effectively reduce the uncertainty in total plutonium inventory in each reach, a stratified random sample allocation process was applied (using calculations based on equation 5.10 in Gilbert 1987, 56179). To evaluate uncertainty in this sample allocation process, Monte Carlo calculations were performed using the Crystal Ball version 4 add-in to Microsoft Excel software. These calculations used available data on the area, thickness, and plutonium concentration in each geomorphic unit and sediment facies to help determine the number of samples to be collected from each unit and each facies. For example, a unit with a relatively large volume of post-1942 sediment, high plutonium concentration, and/or high variability in plutonium concentration would be assigned more samples than a similar unit with small volume, low concentrations, and/or low variability in plutonium concentration.

In all reaches a series of samples were also collected for limited-suite analyses, with this limited suite including analytes measured above background values in the full-suite analyses. The limited suite included metals, polychlorinated biphenyls (PCBs) and pesticides, and select radionuclides and is discussed in Section 3.0. A primary goal of these limited-suite analyses was to evaluate to what degree concentrations of plutonium were correlated with concentrations of the other analytes and hence to what degree they are collocated within the same sediment deposits. Sample collection for limited-suite analyses included sample intervals that had yielded the highest plutonium concentration within each reach as well as intervals with more representative plutonium concentration and including the range of geomorphic units and sediment facies that had been identified.

2.3 Results

2.3.1 Reach P-1

2.3.1.1 Physical Characteristics

Reach P-1 is in a part of Pueblo Canyon with a relatively steep, narrow, rocky canyon floor. The area that has been impacted by post-1942 floods averages approximately 13 m in width, including most of the canyon floor. The areal distribution of the geomorphic units is shown on Figures 2.1-1, 2.3-1, and 2.3-2, and topographic relations are illustrated in the cross sections of Figure 2.3-3. Physical characteristics of the geomorphic units in P-1 are summarized in Table 2.3-1. Data on particle size and unit thickness are presented in Table B3-1, Table B3-4, and Figure B2-1.

The active channel, c1, averages 2 to 3 m in width and has a bed composed of gravel and coarse sand. The active channel is usually bordered by abandoned post-1942 channel units (c2, c2b) that average approximately 0.8 to 0.9 m above the channel and are capped by an average of approximately 0.6 to 0.9 m of relatively fine-grained overbank sediments dominated by fine sand. Unit c2b, of limited areal extent, is indistinguishable from typical c2 units except it has subsurface layers with the highest field alpha radiation measurements and the highest plutonium concentrations in this reach. The undisturbed c2 units are typically 2 to 3 m in combined width, although part of the original extent of c2 and c2b may be buried beneath fill associated with construction of a dirt road and emplacement of sewer lines.

Active floodplains (f1) in P-1 are typically 4 to 5 m wide, 0.9 to 1.7 m above the active channel, and capped by 0 to 0.4 m of overbank sediments. Large areas of floodplains have probably been disturbed by the road and sewer line. Boulders are common in this reach, contributing to large spatial variations in the thickness of overbank facies sediment and affecting erosion and deposition during floods.

2.3.1.2 Radiological Characteristics

Field measurements of gross gamma and beta radiation in reach P-1 indicated that levels of gamma- and beta-emitting radionuclides, such as cesium-137 and strontium-90, were not high enough to allow contaminated areas to be distinguished from background radiation using field instruments. Therefore, these measurements were not used in the geomorphic mapping or to help select most sample sites, although the site of the highest fixed-point gamma radiation was selected for full-suite analyses. A summary of the gross gamma and beta radiation measurements and maps showing measurement locations are presented in Appendix B-5.0. In contrast, fixed-point field measurements of alpha radiation indicated that levels of alpha-emitting radionuclides such as plutonium-239,240 were locally high enough to allow identification of the areas of highest plutonium concentration; these measurements are discussed in more detail in this section. Supplemental information on field alpha radiation measurements is included in Appendix B-5.0.

Alpha radiation clearly above local background values was measured in the c1, c2, c2b, and f1 geomorphic units in P-1 East between Acid Canyon and Walnut Canyon. However, except for the c2b unit, most measurements were within background ranges of approximately 3 to 15 counts per minute (cpm) measured upstream of Acid Canyon (Figure 2.3-4). The c2b unit was designated as that part of the c2 unit where relatively high alpha radiation measurements were consistently measured from subsurface layers. No measurements above background values were obtained downstream of Walnut Canyon, suggesting lower plutonium concentrations in that part of P-1 East.

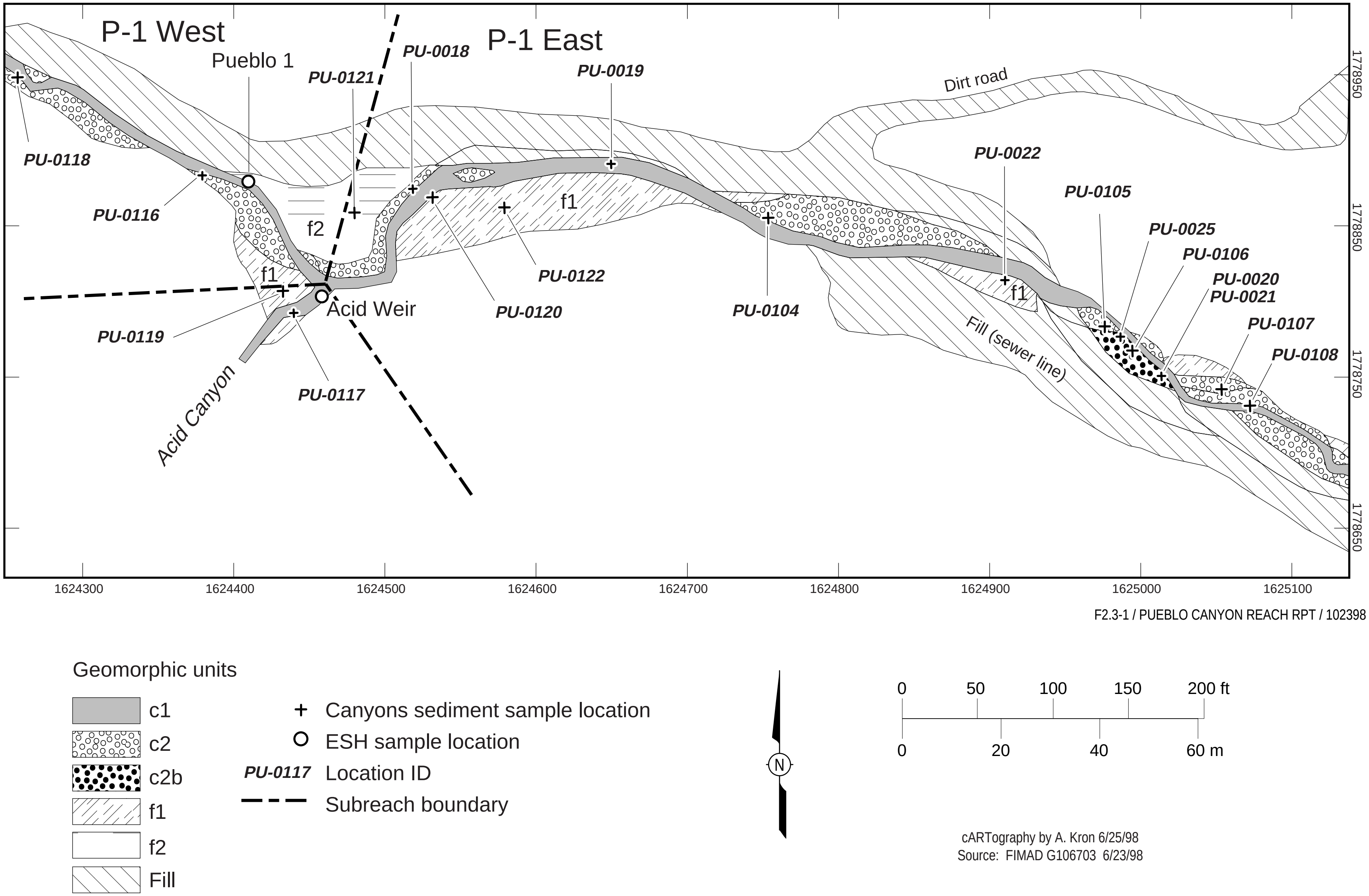


Figure 2.3-1. Geomorphic map of west half of reach P-1 showing sample locations.

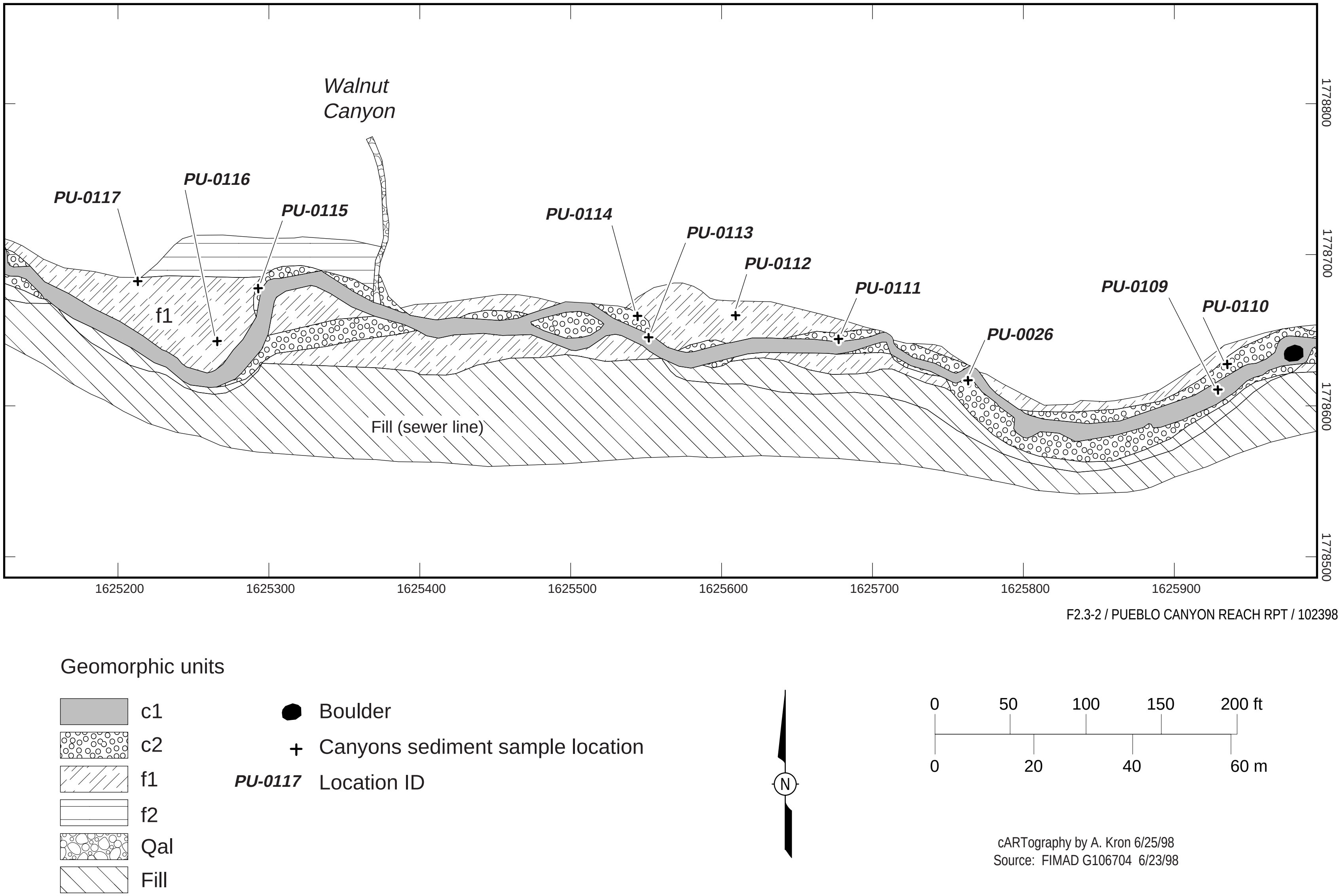


Figure 2.3-2. Geomorphic map of east half of reach P-1 within P-1 East showing sample locations.

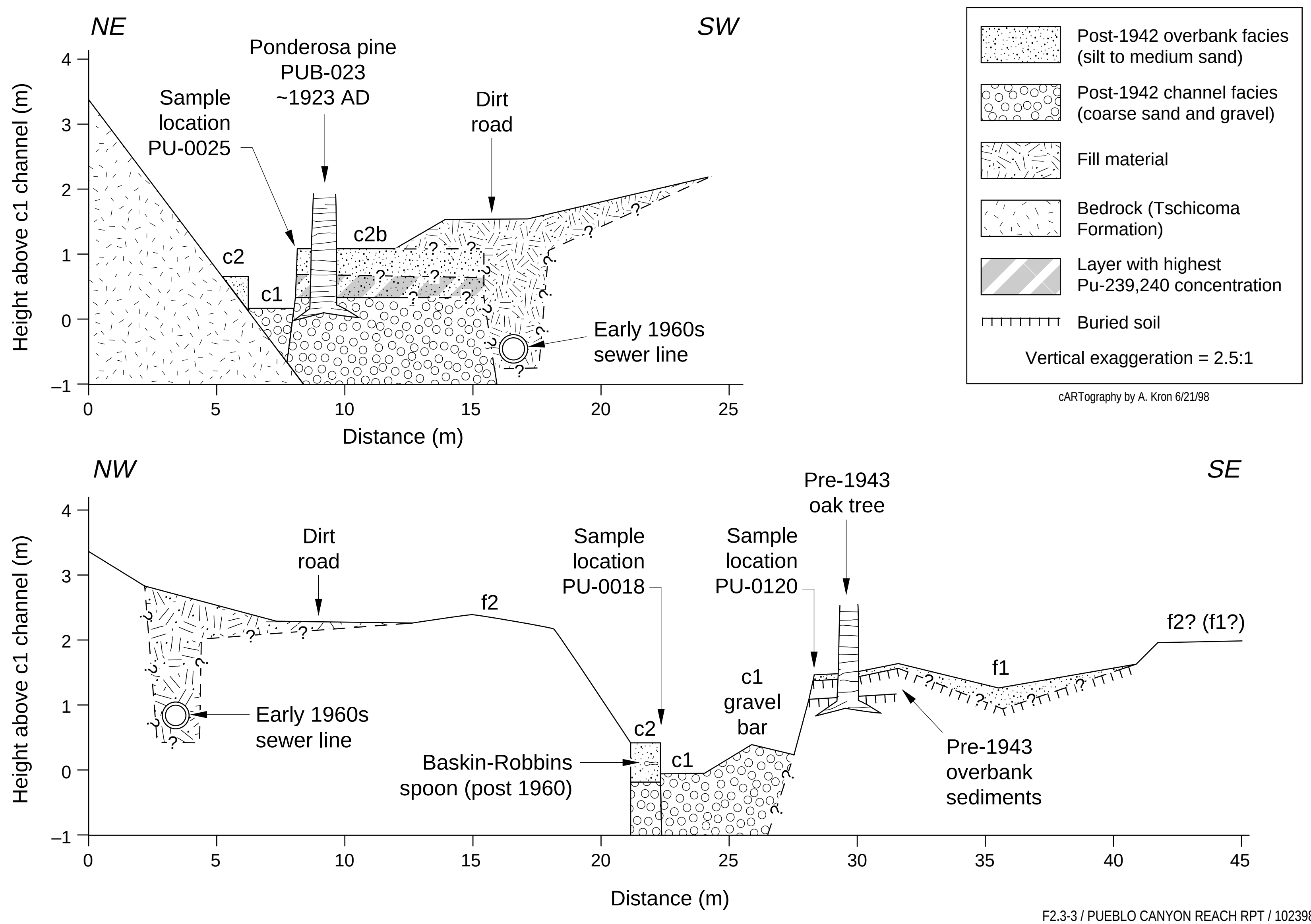


Figure 2.3-3. Schematic cross sections in reach P-1 East showing approximate thickness of post-1942 sediment and relations between geomorphic units.

TABLE 2.3-1

GEOMORPHIC MAPPING UNITS IN REACH P-1

Subreach	Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width[a] (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
P-1 West	c1	b	167	2.1	Channel	b	b	b	Active channel
	c2	b	256	3.2	Overbank	b	b	b	Typical abandoned post-1942 channel
		b			Channel	b	b	b	
	f1	b	99	1.2	Overbank	b	b	b	Active floodplain
	f2	b	227	2.8	Overbank	b	b	b	Potentially active floodplain
P-1 East	c1	0	1453	2.8	Channel	<1.0	Coarse sand	Gravelly sand	Active channel
	c2	0.8	1389	2.7	Overbank	0.57 ± 0.22	Fine sand	Sandy loam	Typical abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Gravelly sand	
	fill/c2?		857	1.6	Overbank	<0.57			Possible buried c2 beneath fill
					Channel	<1.0			
	c2b	0.9	72	0.1	Overbank	0.9	Fine sand	Sandy loam	Abandoned post-1942 channel with highest plutonium
					Channel	<1.0	Coarse sand	Gravelly sand	
	fill/c2b?		178	0.3	Overbank	<0.9			Possible buried c2b beneath fill
					Channel	<1.0			
	f1	1.3	2398	4.6	Overbank	0.27 ± 0.17	Fine sand	Sandy loam	Active floodplain
	f2	2.3	455	0.9	Overbank	<0.05			Potentially active floodplain

a. Average unit width uses lengths of 80 m for P-1 West and 520 m for P-1 East.

b. Characteristics are assumed to be the same as in P-1 East.

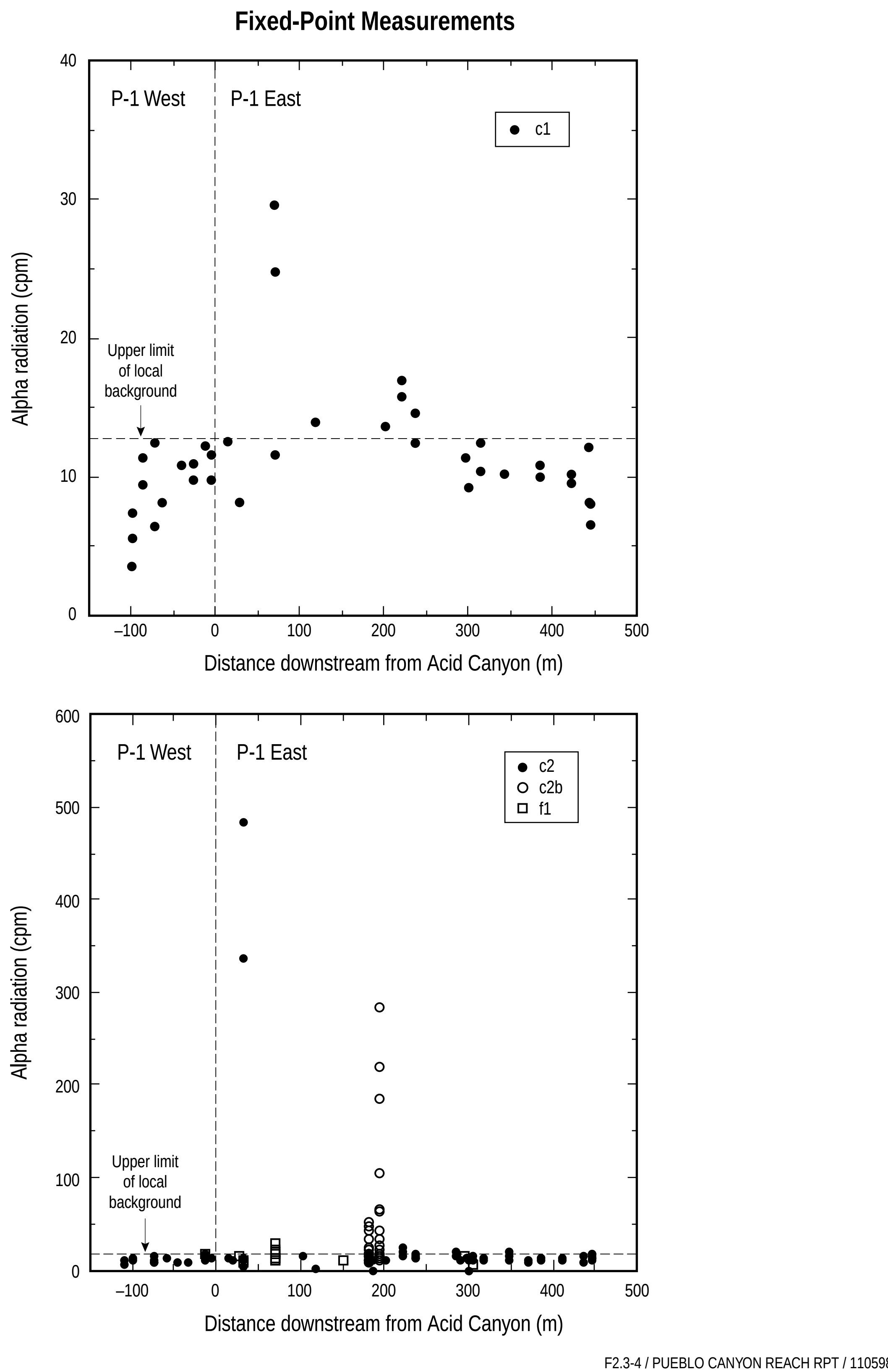


Figure 2.3-4. Plots of alpha radiation measurements in reach P-1 plotted against distance from Acid Canyon.

In sediment layers displaying alpha radiation above background values, field measurements commonly varied greatly, indicating significant heterogeneity in the distribution of plutonium and also the presence of discrete particles of plutonium. The highest alpha measurement of 485 cpm was made at the surface of a c2 unit a short distance downstream of Acid Canyon (fixed-point site P1-20, sample location PU-0018), and the presence of a discrete microscopic particle of plutonium was indicated by the observation that the count rate dropped rapidly to background values as the instrument was moved approximately 10 cm laterally. Similarly, the highest alpha measurement within the c1 unit, 30 cpm (fixed-point site P1-24, sample location PU-0019), seemed to record a discrete particle of plutonium on the surface of the active stream channel as the count rate again dropped rapidly when the instrument was moved laterally.

The variability in alpha radiation was also explored by obtaining 2 to 6 measurements of sediment from some surface and subsurface layers after spreading sediment on a pie tin to obtain smooth surfaces. These multiple measurements included remeasurement of the same spot on a smoothed surface, remeasurement of the same aliquot after it had been mixed in the pie tin, and measurement of sediment from an adjacent location in the same layer. These measurements suggested that the largest source of variability was local heterogeneity in the distribution of plutonium, particularly in layers with the highest levels of plutonium. For example, the subsurface layer with the highest alpha radiation measurements (70 cm deep at fixed-point site P1-73, sample location PU-0020) yielded 105 and 185 cpm from the first prepared surface, 220 and 283 cpm after mixing the same aliquot, and 64 and 65 cpm from a separate aliquot of sediment from an adjacent spot (Figure 2.3-5). The aliquot that had yielded the 105 to 283 cpm measurements was saved for laboratory analysis, providing the highest plutonium-239,240 concentration from Pueblo Canyon (502 pCi/g, sample 04PU-96-0128), although later collection of an additional sample from this same depth approximately 10 to 20 cm away yielded a much lower value (25 pCi/g, sample 04PU-96-0145).

2.3.1.3 Geomorphic History

Geomorphic processes within reach P-1 since 1942 have included the lateral migration of the active channel within a relatively narrow area, represented by the width of the c1 and c2 units, and the occasional overtopping of higher pre-1943 surfaces during floods. Some vertical changes in the elevation of the stream bed have occurred locally, resulting in young (post-1942) overbank facies sediments in some places occurring below the elevation of the present channel and channel gravels in some places occurring higher, but these vertical changes seem to be relatively minor. The abundant boulders have likely restricted the ability of the stream to incise during floods, and on average the stream bed has probably been within 0.5 m of its present elevation since 1942.

Most of the post-1942 overbank facies sediment and associated contaminants present within P-1 are stored within the c2 units relatively close to the active channel. These sites are particularly susceptible to remobilization by lateral bank erosion during floods, and the average residence time for sediment at these sites is probably less than 50 years. This conclusion is based on the limited distribution of overbank sediment with the highest plutonium concentrations, represented by the c2b unit, which probably dates to the early post-1944 period when plutonium releases were highest. In most places overbank sediment of this age has apparently been remobilized by subsequent floods, such that only fairly small pockets remain. In contrast, the smaller volume of overbank sediment stored on the f1 units has average residence times of greater than 50 years and is less susceptible to remobilization by bank erosion during floods. These areas are most likely to be subjected to occasional overtopping during large floods, resulting in the deposition of additional fine-grained sediment.

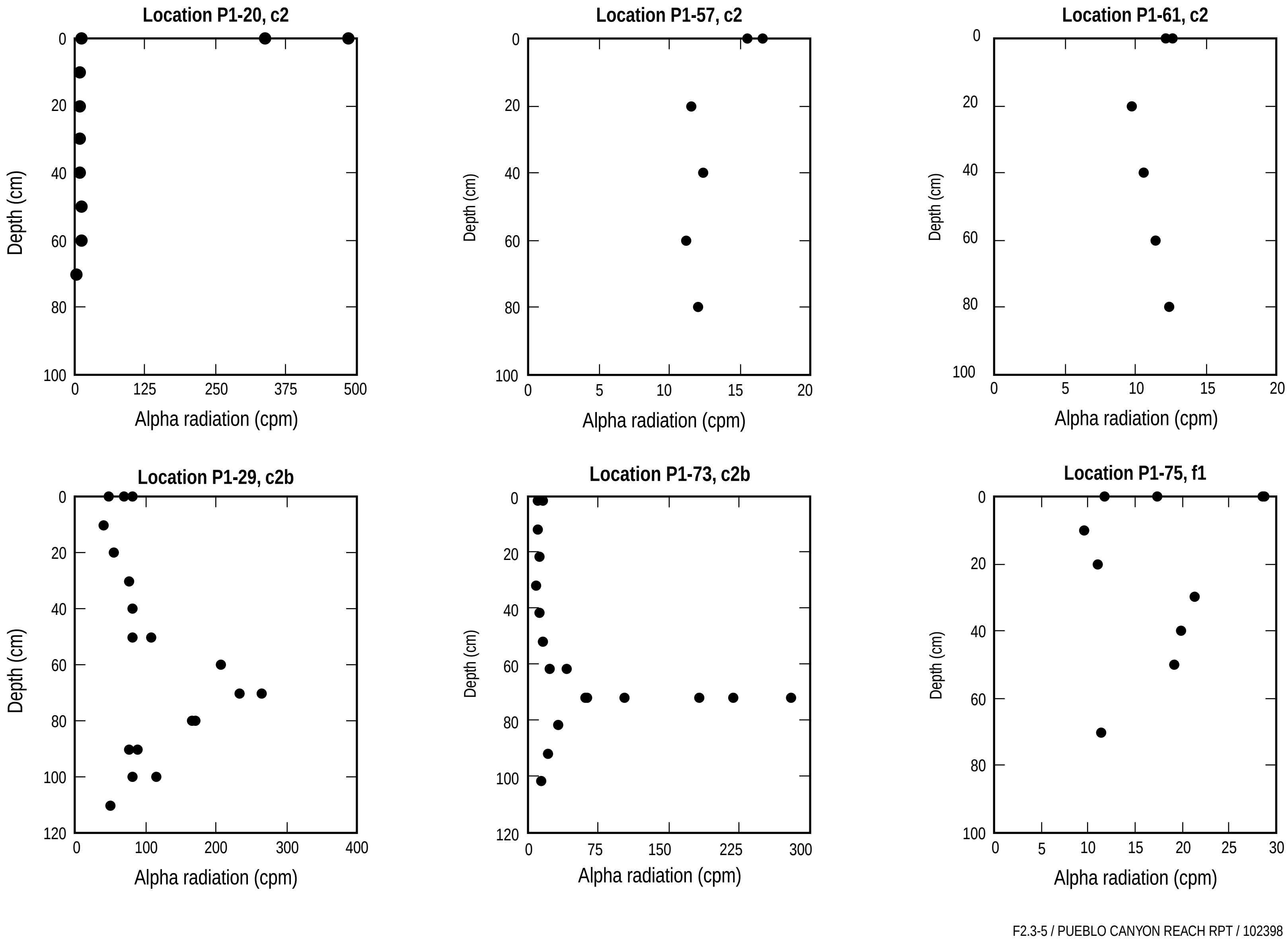


Figure 2.3-5. Plots of alpha radiation in reach P-1 East plotted against depth.

2.3.2 Reach P-2

2.3.2.1 Physical Characteristics

Reach P-2 is in a part of Pueblo Canyon where the canyon floor is broadening and flattening and where stream terraces commonly occur above the level of the active floodplain. A major geomorphic change occurs at the confluence with Kwage Canyon (at the west edge of P-2 East) where the active channel becomes much wider and relief across the historic channel units decreases. The area that has been impacted by post-1942 floods averages approximately 24 m in width in P-2 West and 38 m in P-2 East, resulting in wider dispersion of contaminants in P-2 than in P-1. The areal distribution of the geomorphic units is shown on Figures 2.1-2, 2.3-6, and 2.3-7, and topographic relations are illustrated in the cross sections of Figures 2.3-8 and 2.3-9. Physical characteristics of the geomorphic units in P-2 are summarized in Table 2.3-2. Data on particle size and unit thickness are presented in Tables B3-2 and B3-6 and Figures B2-2 and B2-3.

The active channel, c1, averages 2 to 3 m in width in P-2 West and has a bed composed of gravel and coarse sand. It averages 6 to 7 m in width in P-2 East where the bed is dominated by coarse sand. The active channel is usually bordered by abandoned post-1942 channel units (c1b, c2, c3) that are capped by 0.1 to 0.8 m of relatively fine-grained overbank sediments dominated by fine or very fine sand and that vary in width and height between P-2 West and P-2 East (Table 2.3-2). The abandoned channel units average approximately 10 m in combined width in P-2 West and 15 m in P-2 East, and they are typically lower in P-2 East. In particular, the most widespread abandoned channel unit in each subreach, c2, averages 0.8 m in height in P-2 West but only 0.3 m in height in P-2 East. In P-2 West a sewer line has been buried within the post-1942 geomorphic units, and large parts of the active and abandoned channels have been disturbed by activities associated with its installation. Stratigraphy observed in hand-dug holes within the c2 unit in P-2 East, supported by laboratory analyses, indicates that it is underlain by at least 1.5 m of post-1942 sediment. A 1998 drill hole below the active channel in P-2 East (sample location PU-0174) encountered tuff at a depth of 2.1 m, suggesting a maximum thickness for post-1942 sediments in this subreach.

Active floodplains (f1) average approximately 10 m in width in P-2 West, average approximately 1.2 m above the active channel, and are capped by an average of 0.2 to 0.3 m of relatively fine-grained overbank sediments. Active floodplains in P-2 East are wider but are closer to the channel and have thinner deposits of post-1942 overbank sediments; in P-2 East the f1 units average approximately 17 m in width, are approximately 0.7 m above the active channel, and are capped by an average of approximately 0.1 to 0.15 m of overbank sediments.

2.3.2.2 Geomorphic History

Geomorphic processes that control the distribution of contaminants within reach P-2 West are probably similar to those occurring in P-1. These processes have included the lateral migration of the active channel within a relatively narrow area, represented by the width of the post-1942 channel units, and the occasional overtopping of higher pre-1943 surfaces during floods. Significant vertical changes in the channel bed may also have occurred, but these cannot be defined because of the extensive disturbance of the canyon floor associated with the sewer line. Net aggradation of the stream bed may have occurred, as seen downstream in P-2 East, but significant incision may also have occurred during floods in August 1991 that caused damage to the sewer line (Los Alamos Monitor 1991, 58669).

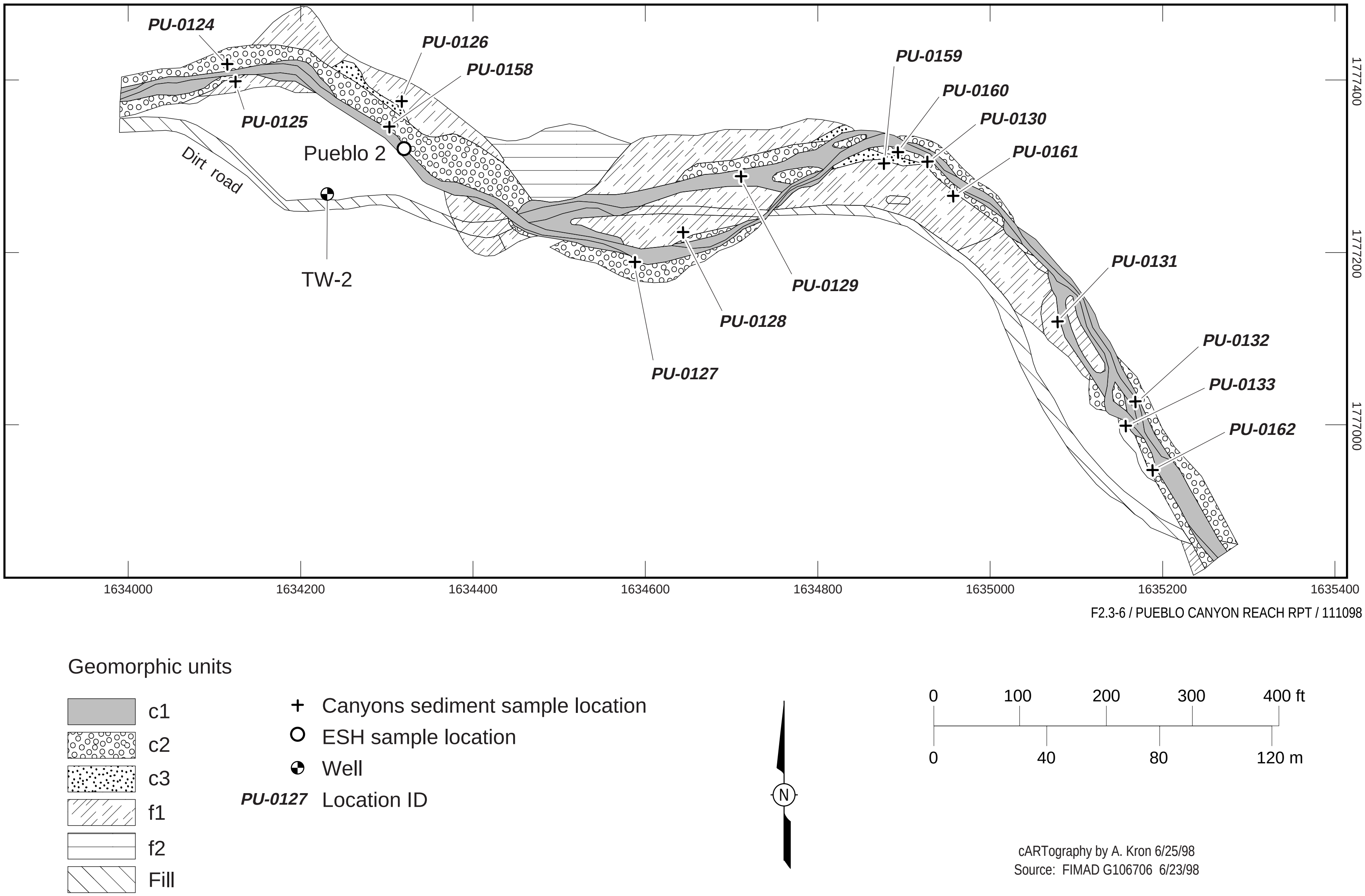


Figure 2.3-6. Geomorphic map of reach P-2 West showing sample locations.

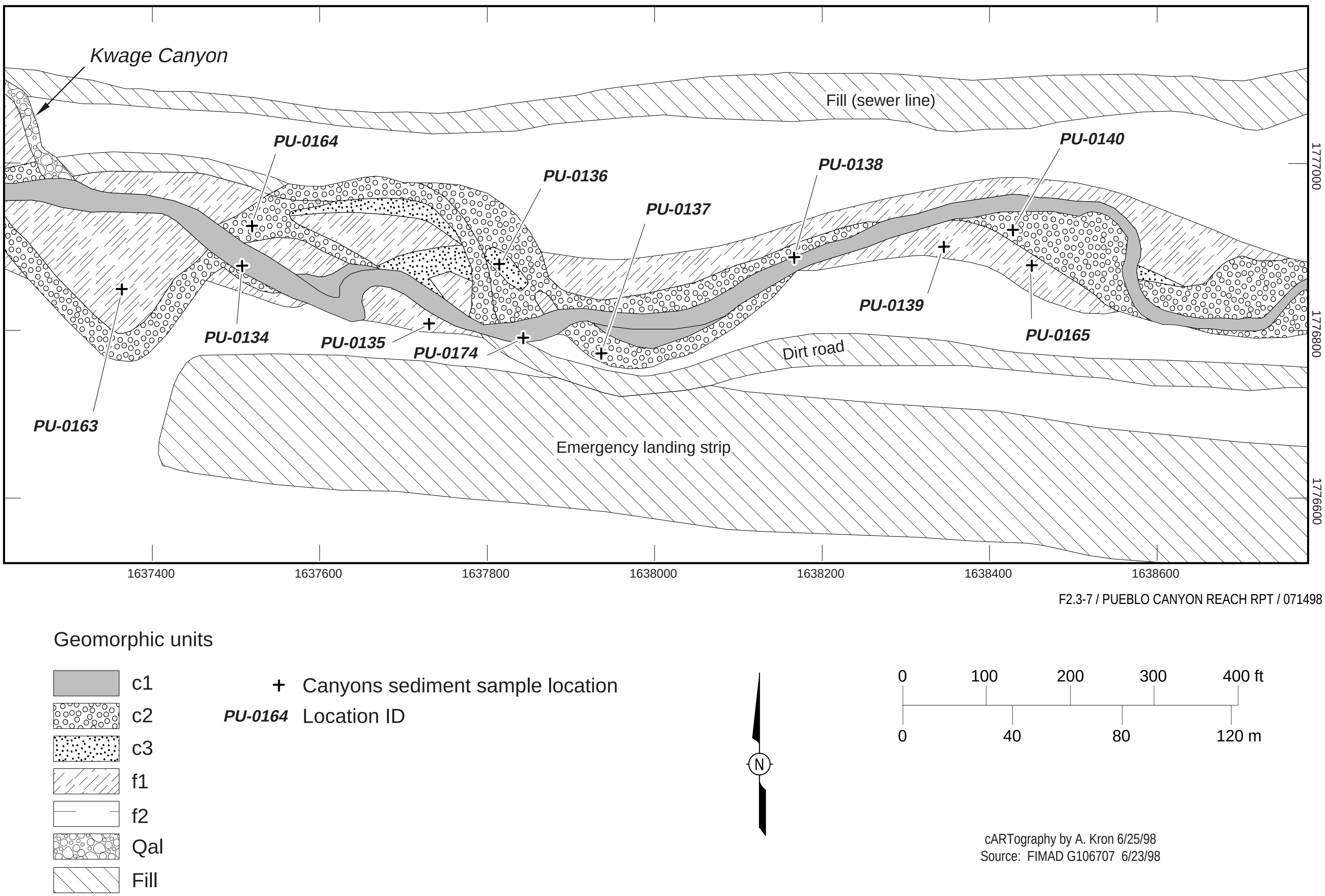


Figure 2.3-7. Geomorphic map of reach P-2 East showing sample locations.

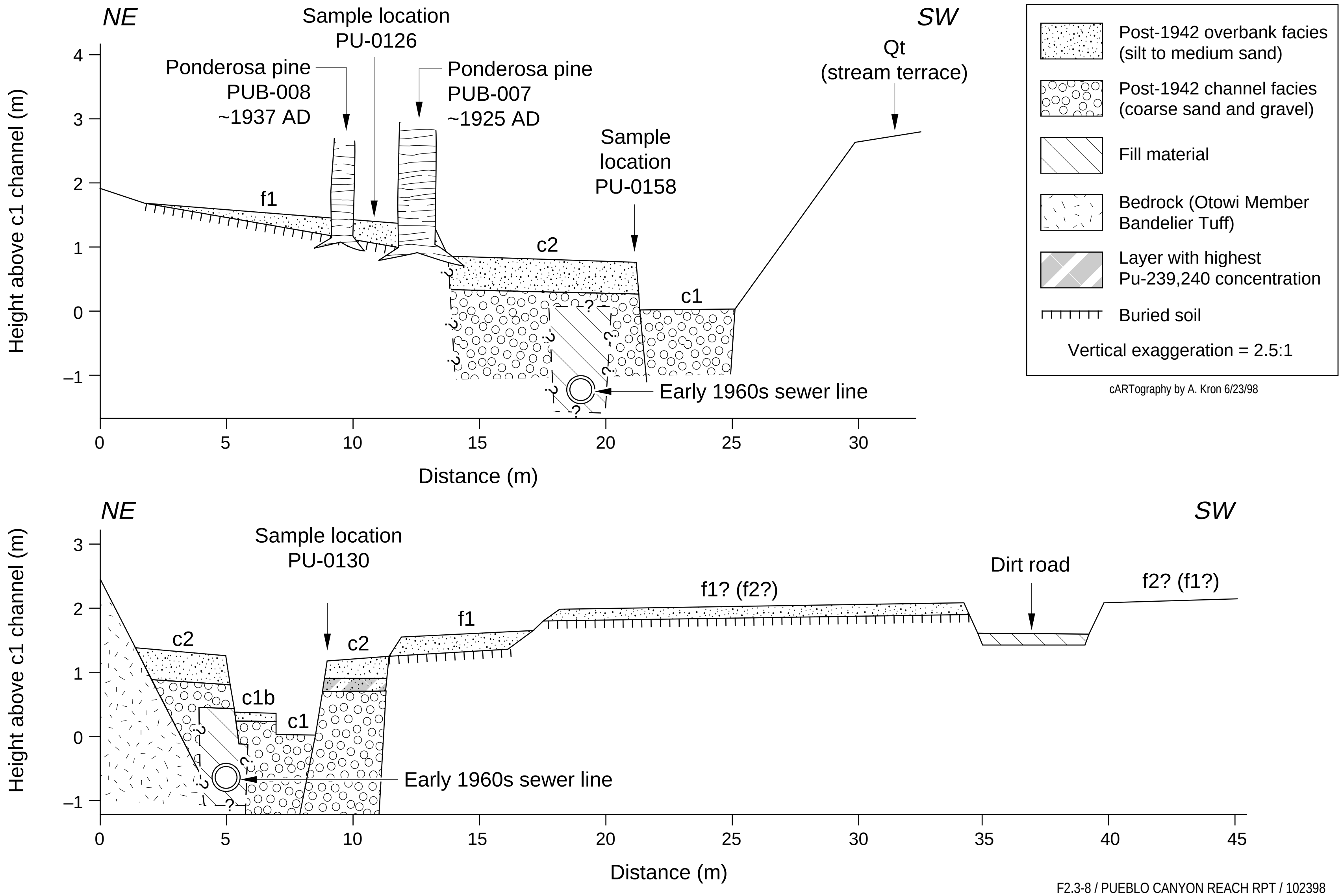


Figure 2.3-8. Schematic cross sections in reach P-2 West showing approximate thickness of post-1942 sediment and relations between geomorphic units.

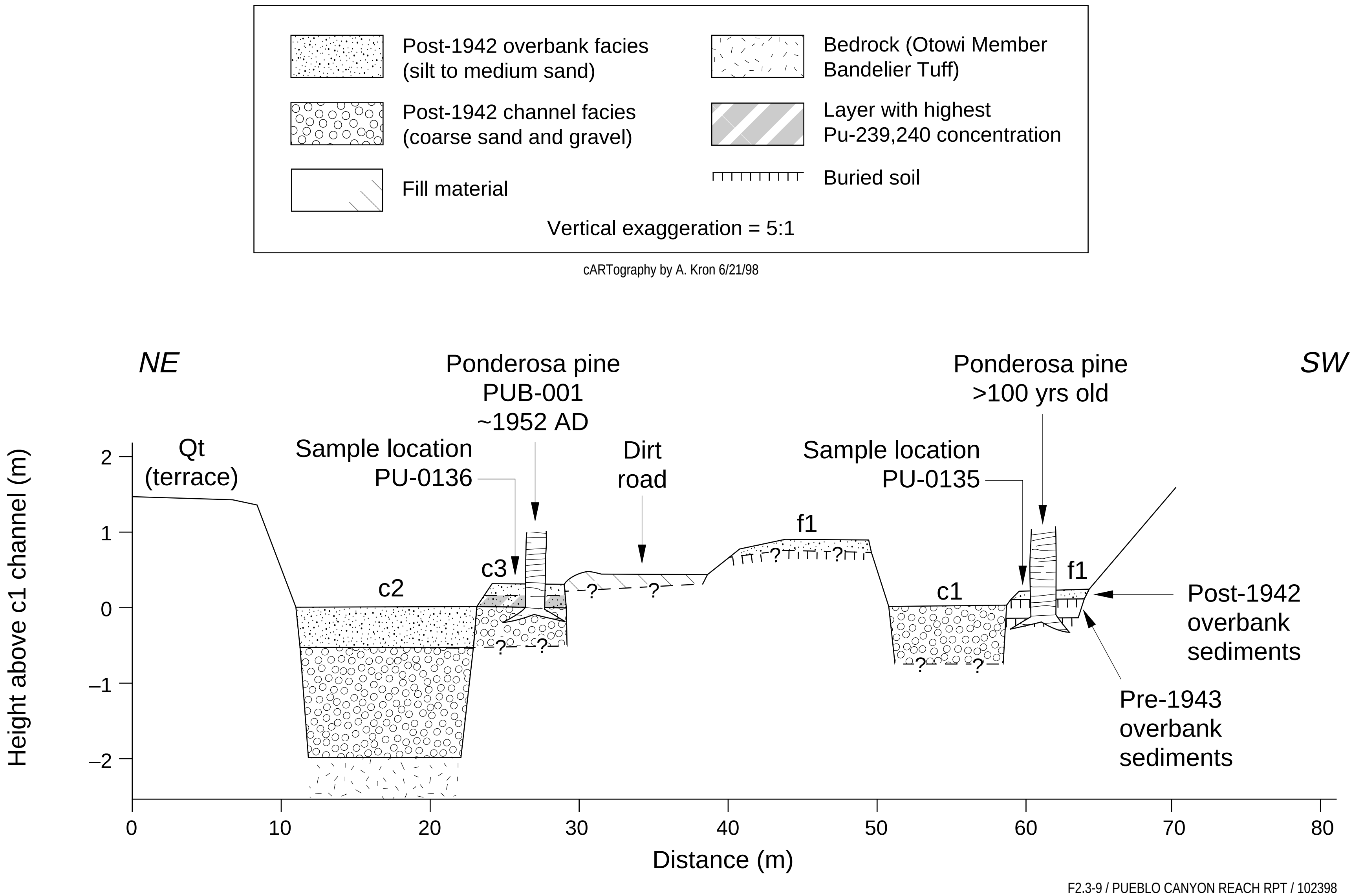


Figure 2.3-9. Schematic cross sections in reach P-2 East showing approximate thickness of post-1942 sediment and relations between geomorphic units.

TABLE 2.3-2

GEOMORPHIC MAPPING UNITS IN REACH P-2

Subreach	Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width* (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
P-2 West	c1	0	1374	2.7	Channel	<2.0	Coarse sand	Gravelly sand	Active channel
	c1b	0.3	1726	3.4	Overbank	0.1 ± 0.1	Fine sand	Sandy loam	Young abandoned channel
					Channel	<2.0	Coarse sand	Gravelly sand	
	c2	0.8	2880	5.6	Overbank	0.41 ± 0.19	Very fine sand	Sandy loam	Typical abandoned post-1942 channel
					Channel	<2.0	Coarse sand	Gravelly sand	
	c3	1	198	0.4	Overbank	0.63 ± 0.13			Possible older abandoned post-1942 channel
					Channel	<2.0			
	f1	1.2	5044	9.9	Overbank	0.27 ± 0.22	Fine sand	Sandy loam	Active floodplain
	f2	1.6	863	1.7	Overbank	<0.05			Potentially active floodplain
P-2 East	c1	0	3114	6.8	Channel	2.0	Coarse sand	Loamy sand	Active channel
	c1b	0.2	297	0.6	Overbank	0.13 ± 0.06			Young abandoned channel
					Channel	2.1			
	c2	0.3	5798	12.6	Overbank	0.5 ± 0.28	Very fine sand	Sandy loam	Typical abandoned post-1942 channel
					Channel	1.8	Coarse sand	Sand	
	c3	0.7	743	1.6	Overbank	0.25 ± 0.14	Very fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	<1.0	Coarse sand	Sand	
	f1	0.7	7613	16.6	Overbank	0.13 ± 0.12	Fine sand	Sandy loam	Active floodplain

*Average unit width uses lengths of 510 m for P-2 West and 460 m for P-2 East

Geomorphic processes within P-2 East since 1942 have apparently included extensive aggradation of the canyon floor, such that the present elevation of the stream bed is 1.5 m or more above its elevation earlier in the post-1942 period. The relatively low heights of the c2 and f1 surfaces, compared with most other subreaches, are consistent with an aggrading system. However, tree-ring dating indicates that at one location (PU-0136) the elevation of the present channel is similar to the channel location at or before 1952 (tree PUB-001, Table B1-1), suggesting that both channel incision and subsequent aggradation may have occurred since 1952. In addition, major lateral shifting of the channel has also occurred, with meanders being cut off by the channel in one or more floods between 1981 and 1991 such that large areas of abandoned channel are removed tens of meters from the present channel (Figure 2.3-10). This process has probably been most effective during periods of channel aggradation when floods are able to overtop higher surfaces and occupy new locations. Lateral erosion of banks of up to 15 m has also occurred in P-2 East during the 37-year period from 1954 to 1991, for a maximum average rate of 0.4 m/yr.

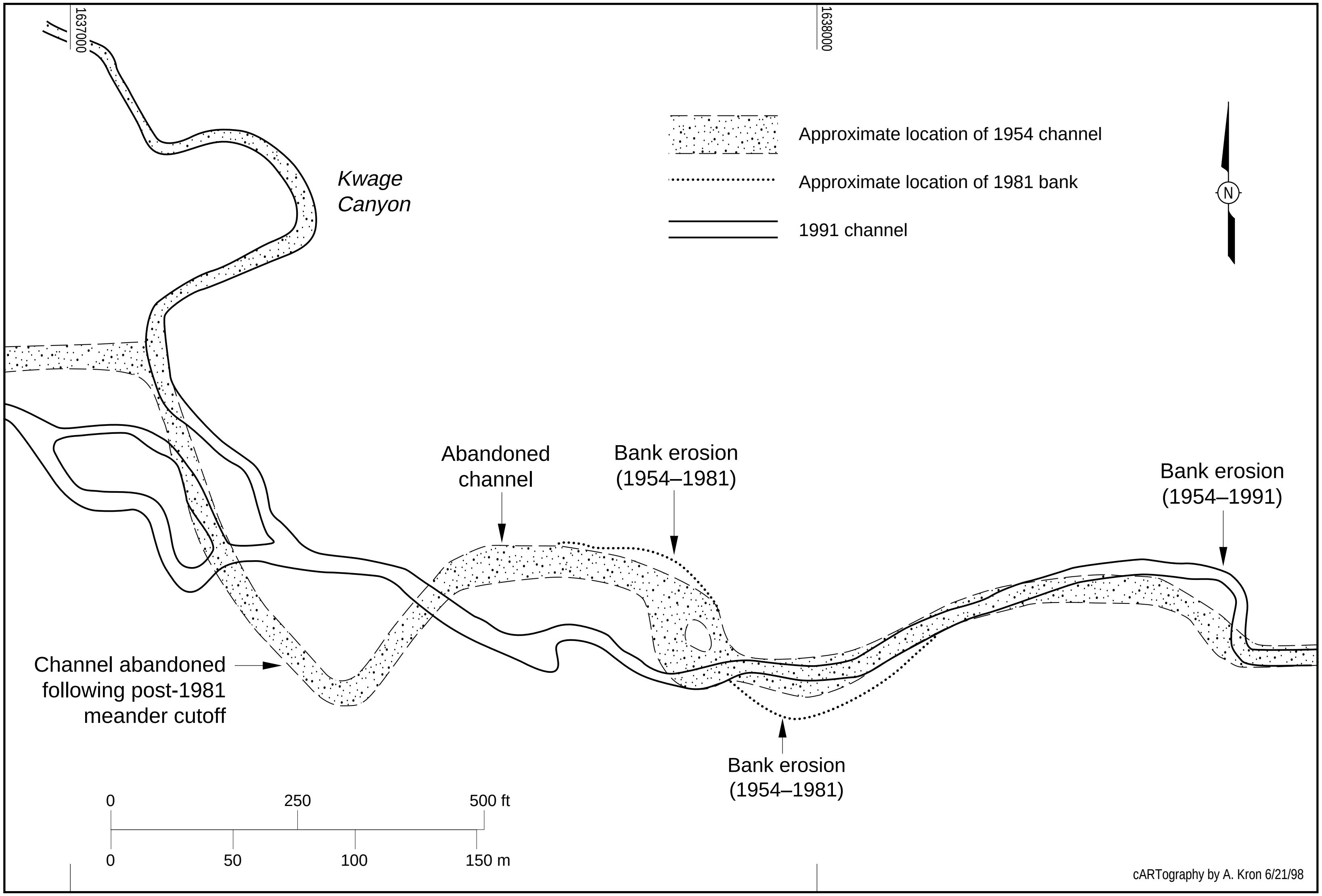
The primary storage sites for post-1942 overbank facies sediment and associated contaminants seems to vary between P-2 West and P-2 East. In P-2 West, roughly 50% of the fine-grained overbank facies sediment occurs with abandoned channel units relatively close to the active channel and hence are relatively susceptible to remobilization during floods; 50% occurs within more stable floodplain settings where the average residence time for sediment exceeds 50 years. In contrast, in P-2 East, approximately 75% of the post-1942 overbank sediment resides in abandoned channel units and approximately 25% in floodplain units; much of the sediment in abandoned channel units is currently isolated from the active channel.

Data on plutonium concentrations within P-2, which are presented in Section 3.3.3, suggest that relatively little sediment from the early post-1942 period is present within this reach. Small pockets of such sediment are probably present within the c2 unit and possibly the c3 unit in P-2 West (e.g., sample location PU-0130), but all samples in P-2 East have relatively low plutonium concentrations.

2.3.3 Reach P-3

2.3.3.1 Physical Characteristics

Reach P-3 is in a part of Pueblo Canyon where the canyon floor is broad and where stream terraces are common above the level of the active floodplain but where the channel begins steepening slightly as it encounters the Puye Formation. Treated effluent from the Bayo Canyon WWTP enters the channel between P-3 West and P-3 East, creating a high water table and relatively dense grassy vegetation in the canyon floor that provide enhanced traps for sediment. The area that has been impacted by post-1942 floods and affected by the dispersion of contaminants averages approximately 25 m in width in P-3 West and increases to approximately 52 m in width in P-3 East. The areal distribution of the geomorphic units is shown on Figures 2.1-3, 2.3-11, and 2.3-12, and topographic relations are illustrated in the cross sections of Figures 2.3-13 and 2.3-14. Physical characteristics of the geomorphic units in P-3 are summarized in Table 2.3-3. Data on particle size and unit thickness are presented in Tables B3-3 and B3-7 and Figures B2-4 and B2-5.



F2.3-10 / PUEBLO CANYON REACH RPT / 102398

Figure 2.3-10. Channel changes in reach P-2 East as determined from historical aerial photographs showing overlays of the channel location in different years.

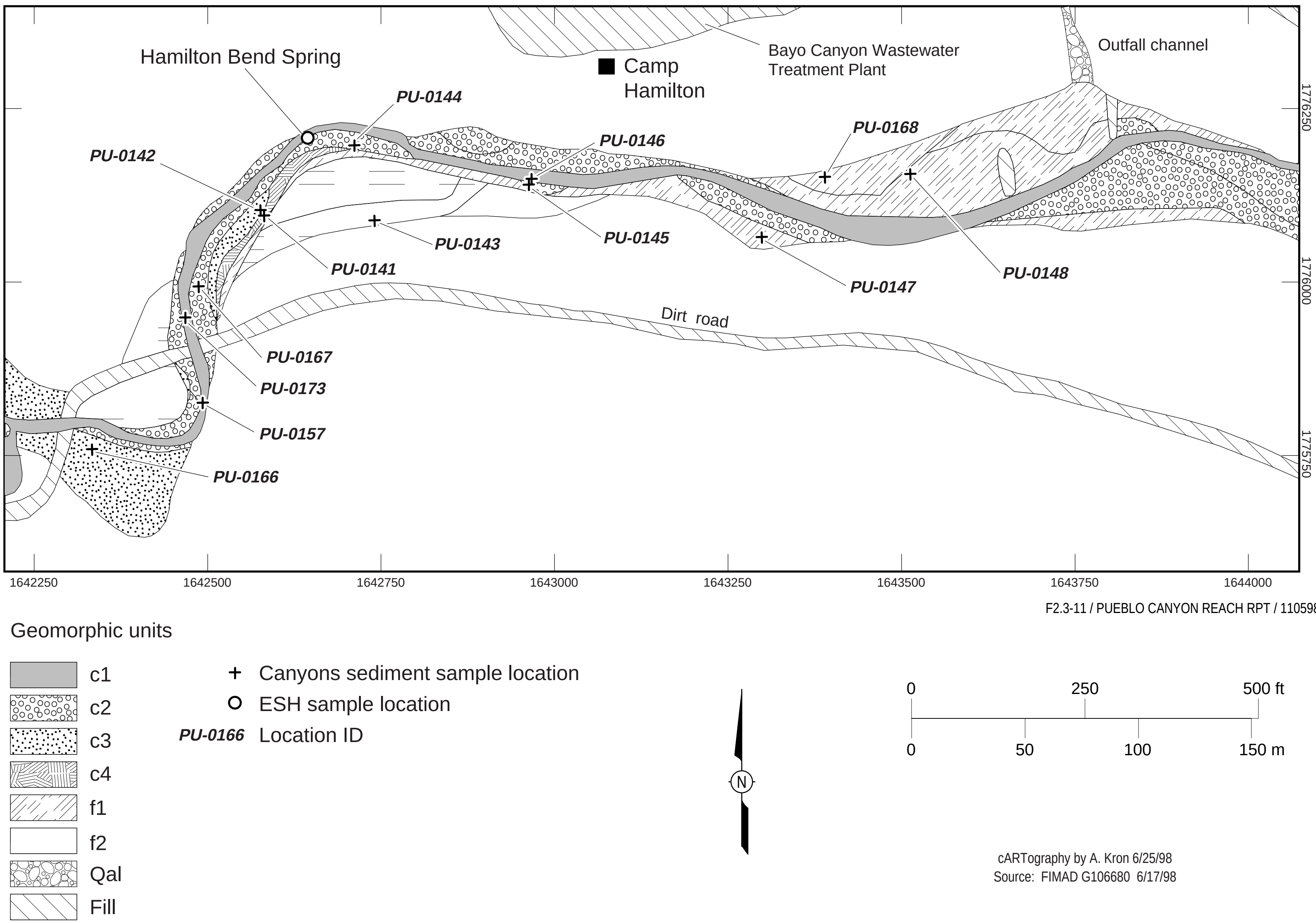


Figure 2.3-11. Geomorphic map of reach P-3 West showing sample locations.

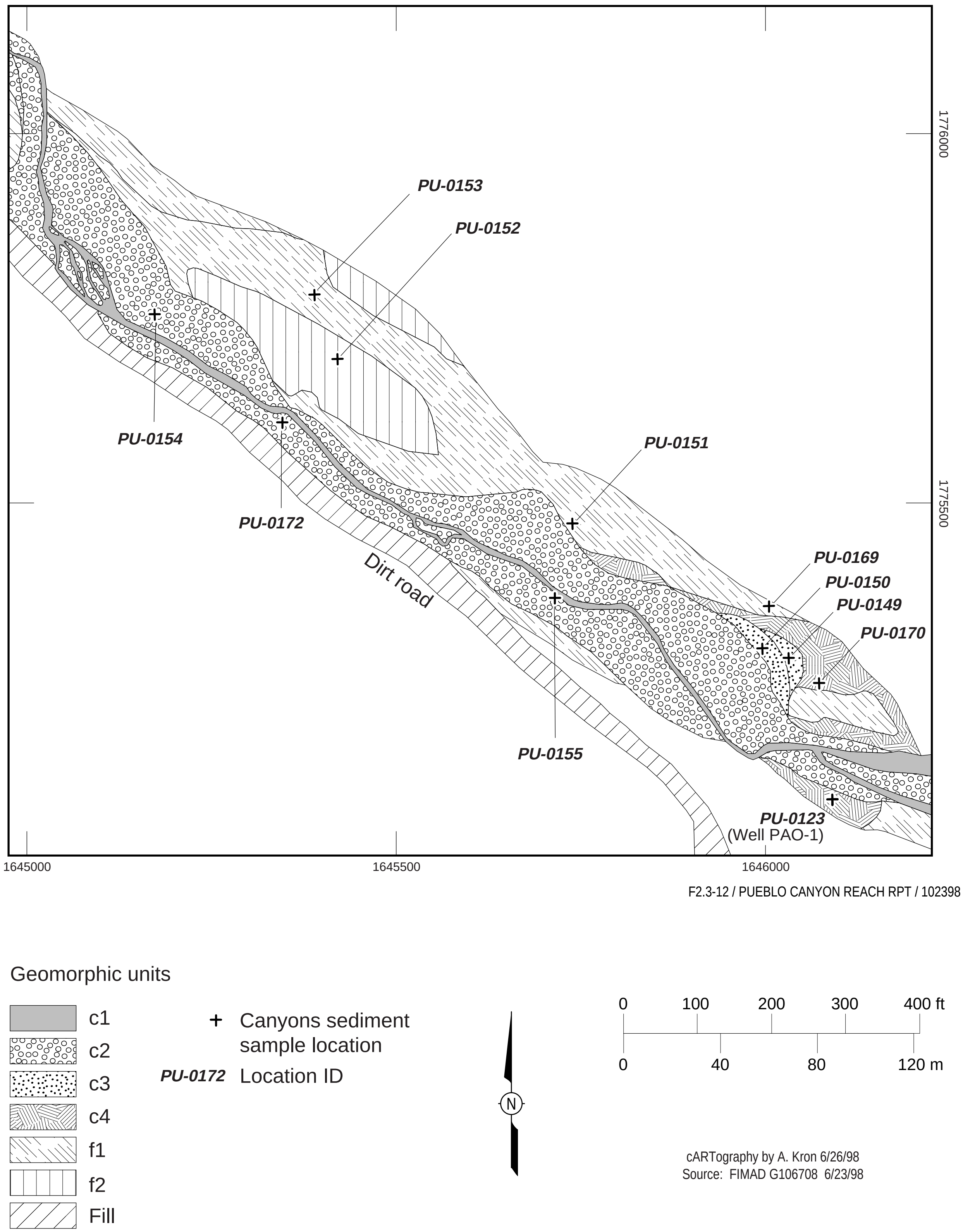


Figure 2.3-12. Geomorphic map of reach P-3 East showing sample locations.

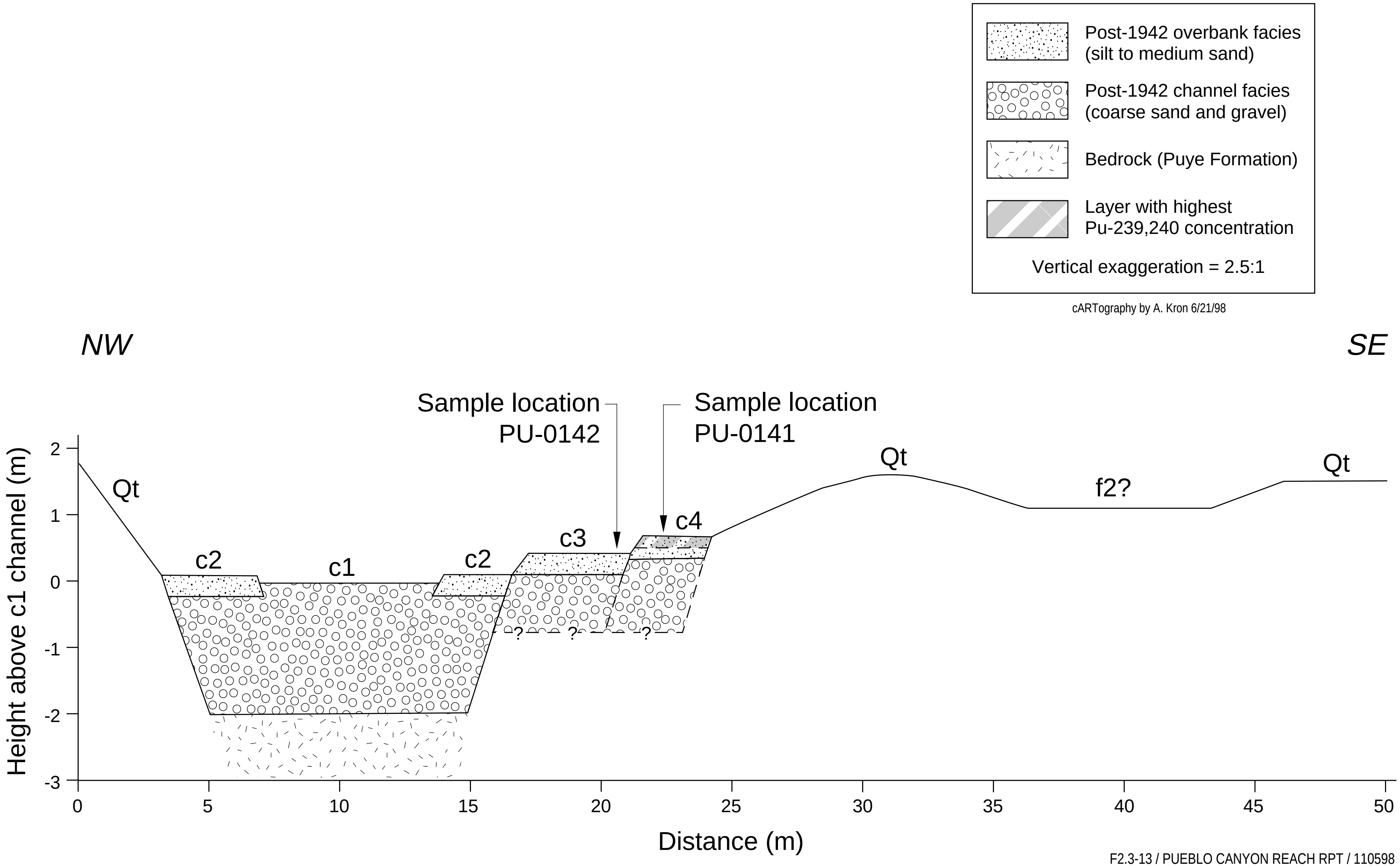


Figure 2.3-13. Schematic cross sections in reach P-3 West showing approximate thickness of post-1942 sediment and relations between geomorphic units.

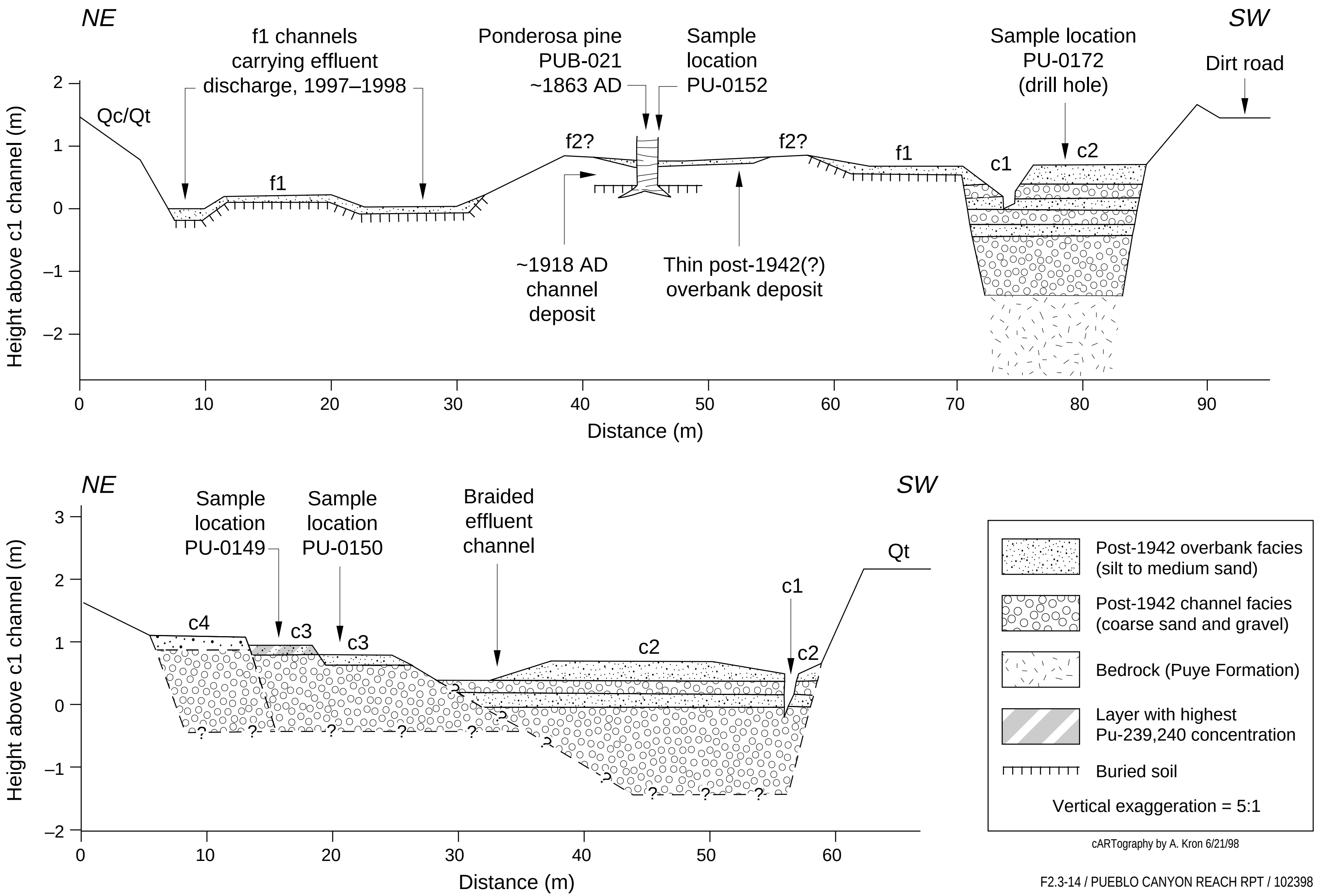


Figure 2.3-14. Schematic cross sections in reach P-3 East showing approximate thickness of post-1942 sediment and relations between geomorphic units.

TABLE 2.3-3

GEOMORPHIC MAPPING UNITS IN REACH P-3

Subreach	Unit	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width* (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
P-3 West	c1	0	2888	5.7	Overbank	0.04 ± 0.07	Fine sand (?)	Sandy loam (?)	Active channel
					Channel	2.0	Coarse sand	Gravelly loamy sand	
	c2	0.15	3471	6.8	Overbank	0.29 ± 0.25	Very fine sand	Sandy loam	Typical abandoned post-1942 channel
					Channel	1.9	Coarse sand	Gravelly sand	
	c3	0.4	1908	3.7	Overbank	0.28 ± 0.15	Very fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	1.0	Coarse sand	Gravelly sand	
	c4	0.5	340	0.7	Overbank	0.22 ± 0.08	Fine sand	Sandy loam	Oldest abandoned post-1942 channel
					Channel	1.0	Coarse sand	Gravelly loamy sand	
	f1	0.3	3855	7.6	Overbank	0.20 ± 0.21	Very fine sand	Loam	Active floodplain
	f2	1.1	4310	8.5	Overbank	<0.05	Fine sand (?)	Sandy loam (?)	Potentially active floodplain
P-3 East	c1	0	1818	3.4	Channel	2.0	Coarse sand	Gravelly loamy sand	Active channel
	c2	0.45	13215	24.5	Overbank	0.49 ± 0.2	Very fine sand	Sandy loam	Typical abandoned post-1942 channel
					Channel	1.5	Coarse sand	Gravelly sand	
	c3	0.8	458	0.8	Overbank	0.08	Very fine sand	Sandy loam	Older abandoned post-1942 channel
					Channel	1.5	Coarse sand	Gravelly sand	
	c4	0.9	1904	3.7	Overbank	0.50 ± 0.18	Fine sand	Sandy loam	Oldest abandoned post-1942 channel
					Channel	3.0	Coarse sand	Gravelly loamy sand	
	f1	0.3	10514	19.5	Overbank	0.09 ± 0.07	Very fine sand	Loam	Active floodplain
	f2	0.8	3348	6.2	Overbank	<0.05	Fine sand	Sandy loam	Potentially active floodplain

*Average unit width uses lengths of 510 m for P-3 West and 540 m for P-3 East

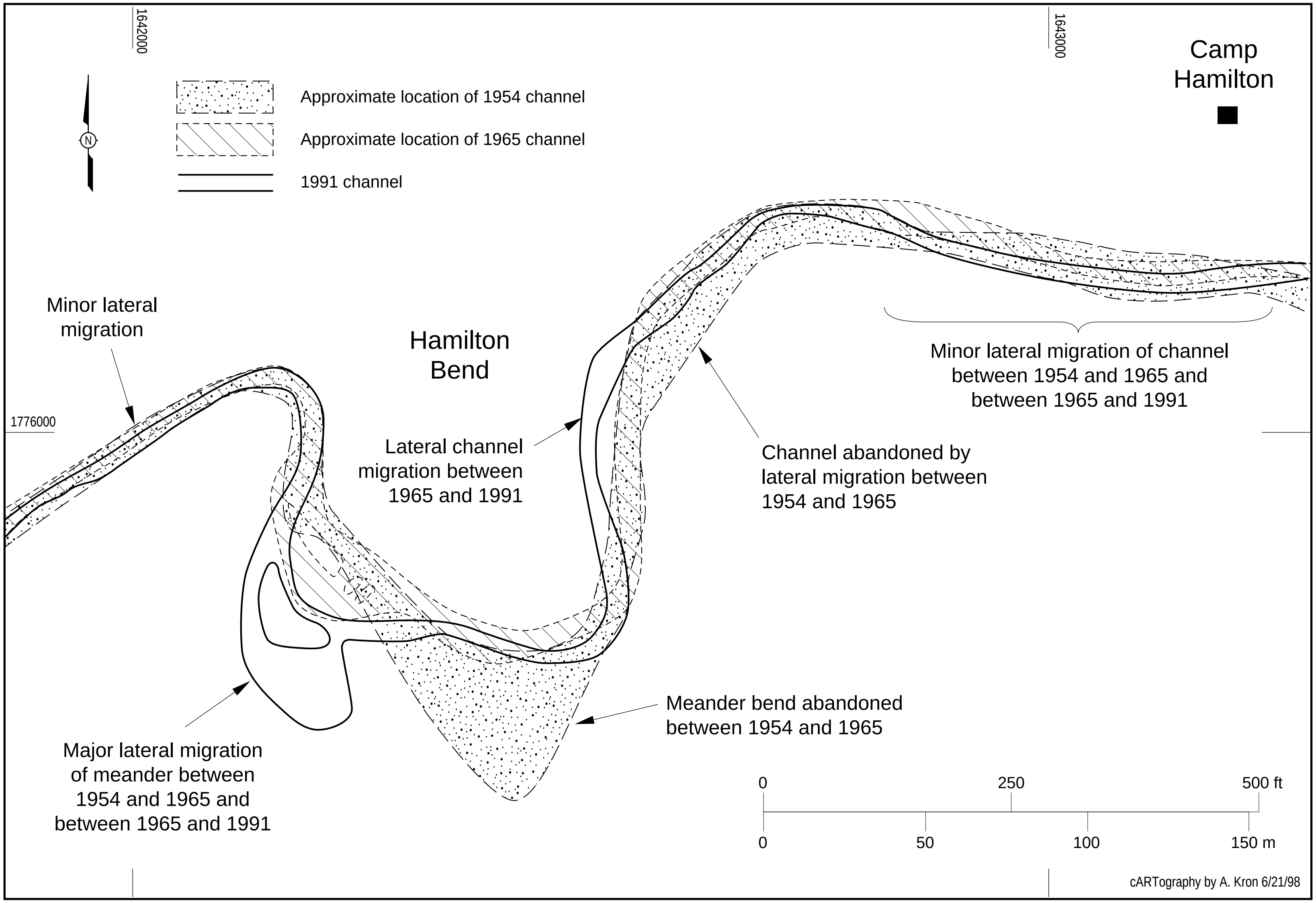
The active channel, c1, averages 5 to 6 m in width in P-3 West with a bed composed of coarse sand and some gravel, bordered by abandoned channel units (c2, c3, c4) that average approximately 11 m in combined width. The c2, c3, and c4 units are relatively low, averaging approximately 0.1 to 0.5 m above the channel, and are capped by an average of 0.2 to 0.3 m of fine-grained overbank sediments. Unit characteristics change dramatically downstream of the WWTP outfall, and the present channel in P-3 East (c1) is typically incised approximately 0.45 m below a broad moist grassy surface (c2), often including two or more braided channels. The c2 surface in P-3 East averages approximately 25 m in width and has interstratified coarse sediments and finer-grained sediments, including an average of at least 0.5 m of fine-grained overbank facies sediment. Large floods, including one in August 1991, spread over virtually this entire surface depositing a combination of coarse and fine sediment layers. In the east part of P-3 East the c2 unit is bordered by higher abandoned channel units (c3, c4) that probably date to the 1950s or earlier. In both P-3 West and P-3 East, the c3 and c4 units are differentiated in part by the higher plutonium concentrations in the c3 channel deposits.

Three drill holes in P-3 provide data on the thickness of alluvium below the channel units. A 1998 drill hole in P-3 West encountered the Puye Formation at a depth of 2.05 m below the active channel (sample location PU-0173), indicating a similar total alluvial thickness here as in P-2 East. Another 1998 drill hole in P-3 East also encountered the Puye Formation at a depth of 2.15 m below the c2 surface (sample location PU-0172). Farther east, alluvial well PAO-1 (sample location PU-0123) encountered the Puye Formation at an approximate depth of 4.1 m below a c4 surface, suggesting locally thicker alluvium and perhaps a thickening of sediment to the east.

Active floodplains (f1) in reach P-3 are relatively low compared with other reaches, averaging only approximately 0.3 m above the active channel. The f1 units average approximately 8 m in width in P-3 West and are capped by an average of approximately 0.2 m of relatively fine-grained overbank sediments. Active floodplains in P-3 East are wider, averaging approximately 20 m in width, but have an average of only approximately 0.1 m of post-1942 overbank sediment. It is notable that the f1 unit in P-3 east is often lower than the c2 unit, such that overtopping of the f1 units in floods occurs readily at present (including during an August 1991 flood). In fact part of the f1 unit is presently traversed by an active channel carrying treated effluent. These characteristics enhance the opportunity for both wide dispersion and deposition of sediments and associated contaminants in P-3 East compared with other reaches and reduce the potential for remobilization under short time scales.

2.3.3.2 Geomorphic History

Geomorphic processes within P-3 West since 1942 have apparently been similar to those in P-2 East, including aggradation of the canyon floor such that the present elevation of the stream bed is probably 1.5 to 2 m above its elevation earlier in the post-1942 period. Associated with this aggradation, broad areas of floodplain in the eastern part of this subreach have been recently overtopped by floodwaters (including in August 1991), and most of the overbank sediment on these floodplains may be relatively young (last 10 to 20 years). In the western part of this subreach, the channel bed elevation in the early post-1942 period (below the c3 and c4 surfaces) was similar to that at present, suggesting that in the last 50 years the channel bed here first incised 1.5 to 2 m and subsequently aggraded a similar amount. During the periods of incision the channel would have been more effective at transporting sediment and associated contaminants provided from upstream than during the period of aggradation. Major lateral shifting of the channel has also occurred in the western part of this subreach at Hamilton Bend, with a meander migrating approximately 40 to 60 m into pre-1943 alluvium and colluvium in multiple floods between 1954 and 1991 (Figure 2.3-15). This bank erosion may locally be an important source of “clean” sediment that dilutes the concentration of plutonium carried by the stream.



F2.3-15 / PUEBLO CANYON REACH RPT / 102398

Figure 2.3-15. Channel changes in reach P-3 West as determined from historical aerial photographs showing overlays of the channel location in different years.

Geomorphic processes within P-3 East since 1942 may have in part been similar to those in P-3 West, including both incision and subsequent aggradation of the canyon floor, although the present morphology is dominated by recent aggradation. In 1954 the area occupied by bare channel surfaces was relatively wide in the east part of P-3 East but had narrowed considerably by 1965, probably associated with channel incision (Figure 2.3-16). In contrast, the channel area in the western part of P-3 East broadened between 1954 and 1965, probably associated with aggradation. The large floodplain area north of the main channel was flooded in August 1991, associated with aggradation of the c2 surfaces. The relatively thin and patchy overbank sediment on this floodplain suggests that the 1991 flood may have been the first since 1942 to overtop this surface. In addition, a side channel carrying treated effluent currently flows through this f1 surface, but is not visible on the 1991 photographs, also indicating recent raising of the stream bed elevation associated with deposition of large amounts of sediment. No older c3 or c4 channel units have been recognized in the western part of this subreach, but they occur to the east and indicate a channel elevation at or before 1954 somewhat higher than at present.

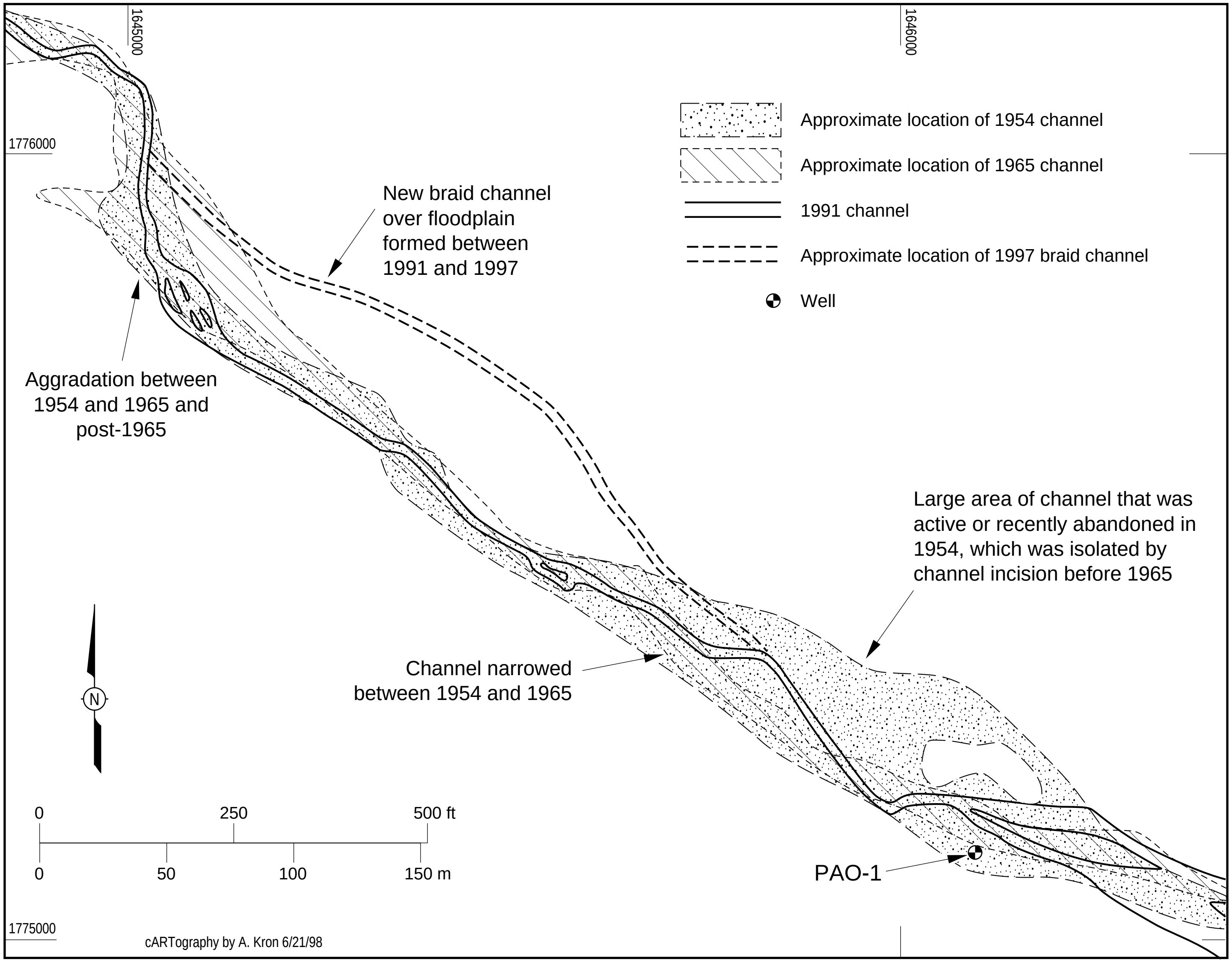
The largest storage sites for overbank facies sediment and associated contaminants in both P-3 West and P-3 East are the c2 channel units, with the total volume of stored overbank sediment being much higher in the eastern subreach. This storage of overbank sediment is probably in part related to the aggradation and associated broadening of the area inundated by floods, decreasing the depth and consequently the velocity of floodwaters. Trapping of overbank sediment is also likely enhanced by the thick grassy vegetation that occurs near the channel in P-3 East. Significant remobilization of this stored sediment would have to involve a shift from aggradation to incision, as has occurred downstream in reach P-4, although it is not certain over what time frame such a shift would occur.

Examination of historic aerial photographs and data on plutonium concentrations within P-3, which are presented in Section 3.3.4, suggest that sediment from the early post-1942 period is present within the c3 and c4 units in both P-3 West and P-3 East. These sediments are largely located away from the active channel in sites not subject to remobilization in most floods. Most of the post-1942 sediment stored within this reach is apparently relatively young and contains relatively low concentrations of plutonium.

2.3.4 Reach P-4

2.3.4.1 Physical Characteristics

Reach P-4 is in the lowest part of Pueblo Canyon above state road NM 502 and the confluence with Los Alamos Canyon. The canyon floor is broad and stream terraces are common above the level of the post-1942 floodplain. The channel is somewhat steeper than in reach P-3, incised into the Puye Formation, and alluvium pinches out east of P-4 East and 120 m upstream of NM 502 where basalt is exposed in the stream bed. Treated effluent from the Bayo Canyon WWTP flows through the length of P-4 creating a high water table and relatively dense grassy vegetation along the channel.



F2.3-61 / PUEBLO CANYON REACH RPT / 111098

Figure 2.3-16. Channel changes in reach P-3 East as determined from historical aerial photographs showing overlays of the channel location in different years.

The most distinctive feature of reach P-4 at present is an incised channel that is 1 to 3 m below the upper surfaces of post-1942 channel units, recording substantial incision that followed a period of aggradation along the channel. During the period of aggradation, floodwaters spread over an exceptionally broad part of the canyon floor, and the area that has been impacted by post-1942 floods and subject to the dispersion of contaminants averages approximately 95 m in width in P-4 West and approximately 105 m in P-4 East. The deepest incision occurs in the western part of P-4 West, and the depth of incision gradually decreases along the length of P-4. At the west end of P-4 West is a major knickpoint in the channel where the incising stream encountered relatively resistant material within the Puye Formation; a knickpoint is a place where the stream channel becomes significantly steeper, and the stream channel is only shallowly incised upstream from the P-4 knickpoint. The areal distribution of the geomorphic units is shown on Figures 2.1-4, 2.3-17, and 2.3-18, and topographic relations are illustrated in the cross sections of Figures 2.3-19 and 2.3-20. Physical characteristics of the geomorphic units in P-4 are summarized in Table 2.3-4. Data on particle size and unit thickness are presented in Tables B3-4 and B3-8 and Figures B2-6 and B3-7.

The active channel (c1) and adjacent sand bars (c1b) that were probably deposited during 1991 floods, as shown by an examination of aerial photographs, average approximately 7 m wide in P-4 West and 24 m wide in P-4 East. A series of young abandoned channel units (c2a, c2b, c2c) occur above the c1 units and below higher abandoned channel units, comprising surfaces that were active during the 1980s but were abandoned by 1991. These units average approximately 12 m in combined width in P-4 West and 2 m in P-4 East. and are largely underlain by coarse sand and gravel with minor fine-grained overbank sediment. The next abandoned channel unit, c3, is only a narrow inset unit in P-4 West but averages approximately 22 m wide in P-4 East where it includes areas of coarse sand both near the present channel and spread broadly over adjacent floodplains; it was locally active until at least 1981 but was completely abandoned by 1986. Older abandoned channel units in P-4 West (c4a, c4b, c5, c6) average approximately 40 m in combined width and are dominantly underlain by coarse sand and some gravel, although they are also locally capped by finer-grained overbank deposits. The c4 units represent channel areas that were active in the 1960s, and the c5 unit represents a large sand deposit from the 1950s. The c6 unit represents an area occupied by the channel in 1935 but abandoned before 1954 where plutonium is generally present above background values in the channel facies sediment. Much of the c6 unit may actually consist of channels abandoned before the first releases of plutonium into Acid Canyon, but age control is not precise enough to determine this. The thicknesses of the post-1942 sediment beneath the higher abandoned channel units is difficult to determine, but it probably ranges from less than 1 m to greater than 2 m based on sedimentologic evidence and plutonium analyses.

The major post-1942 floodplains, f1, average approximately 25 m in width in P-4 West and approximately 56 m in width in P-4 East, but they are presently isolated from the active channel by the recent incision. They are capped by an average of approximately 0.05 m of relatively fine-grained overbank facies sediment in P-4 West and approximately 0.1 m in P-4 East, although these deposits reach up to 0.45 m thick in P-4 East. In P-4 East the f1 unit is similar in elevation to the c3 unit, and c3 sand lobes extend onto the f1 surface in many areas. An additional post-1942 floodplain unit in P-4 West, f1a, averages 11 m in width but is dominated by fine-grained sediment derived from tributary drainages off the south canyon wall; it has plutonium levels only slightly above background values.

2.3.4.2 Radiological Characteristics

Field measurements of gross alpha, beta, and gamma radiation in reach P-4 indicated that levels of all radionuclides were not high enough to allow contaminated areas to be distinguished from background radiation; therefore, these measurements were not used in the geomorphic mapping or to help select sample sites. A summary of the field radiation measurements and maps showing measurement locations are presented in Appendix B-5.0.

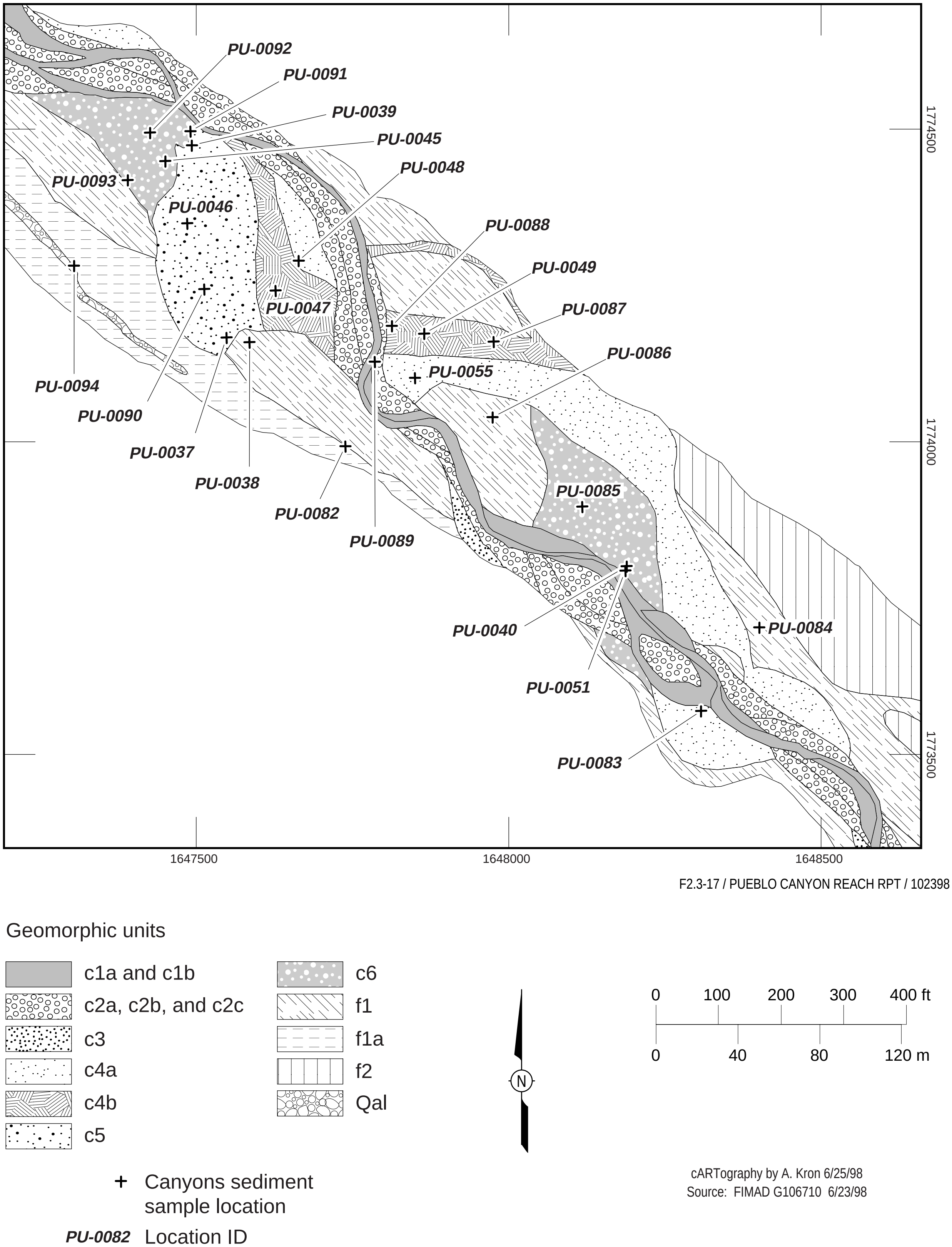


Figure 2.3-17. Geomorphic map of reach P-4 West showing sample locations.

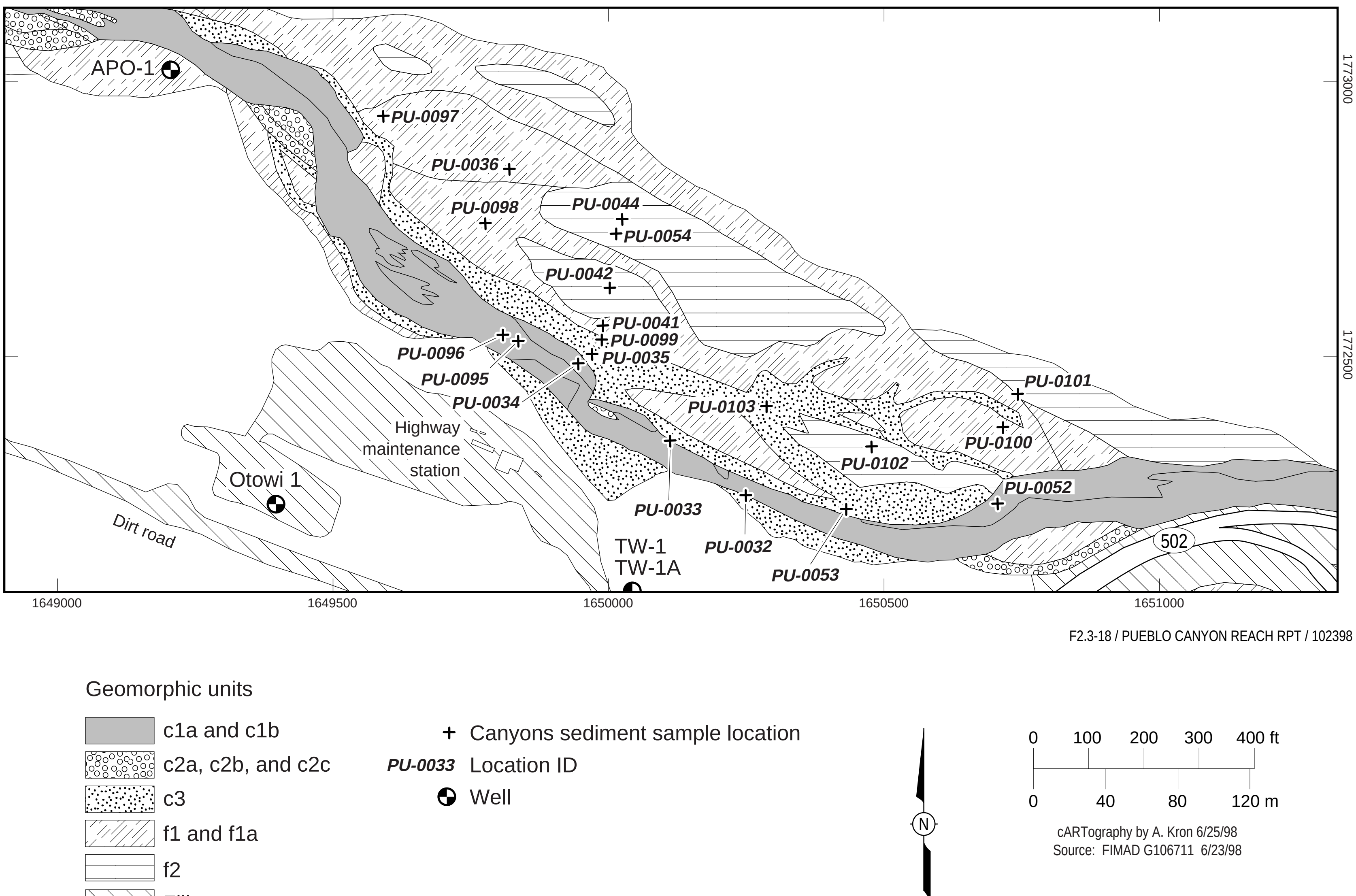


Figure 2.3-18. Geomorphic map of reach P-4 East showing sample locations.

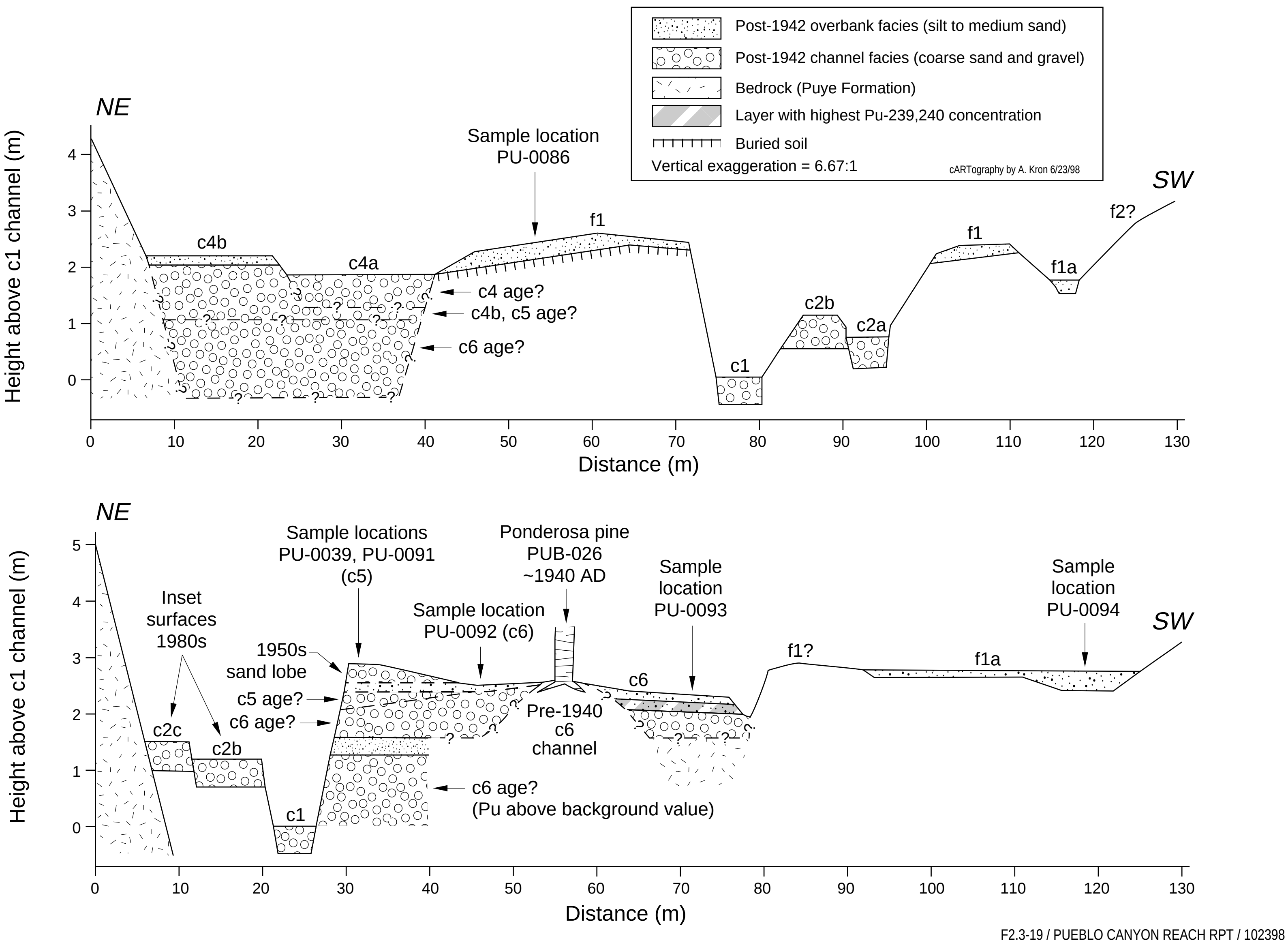


Figure 2.3-19. Schematic cross sections in reach P-4 West showing approximate thickness of post-1942 sediment and relations between geomorphic units.

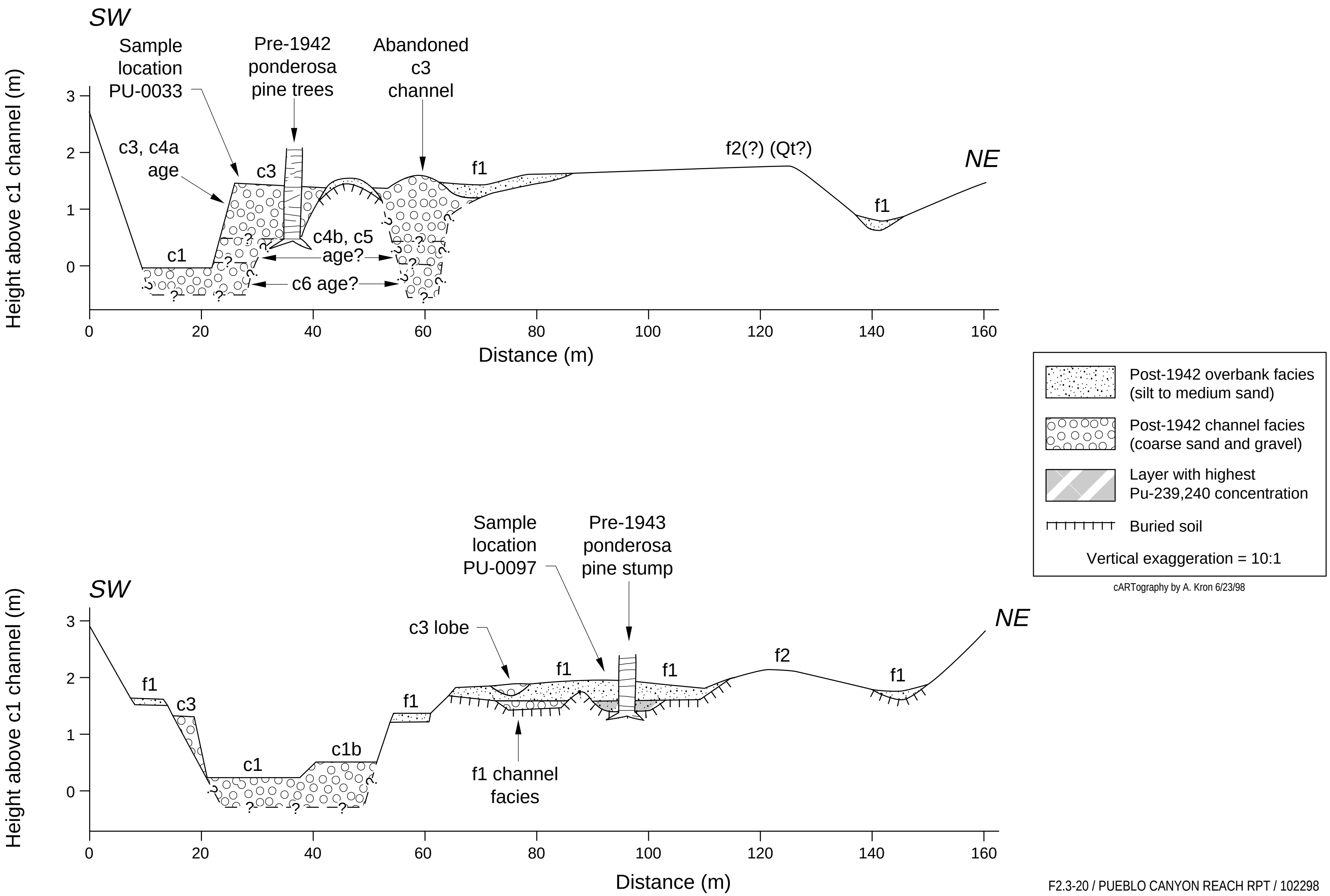


Figure 2.3-20. Schematic cross sections in reach P-4 East showing approximate thickness of post-1942 sediment and relations between geomorphic units.

TABLE 2.3-4

GEOMORPHIC MAPPING UNITS IN REACH P-4

Subreach	Unit(s)	Estimated Average Unit Height Above Channel (m)	Unit Area (m^2)	Average Unit Width* (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
P-4 West	c1	0	1852	3.6	Channel	0.5	Coarse sand	Gravelly sand	Active channel in 1991
	c1–c4a				Overbank	0.05	Very fine sand	Sandy loam	
	c1b	0.4	1653	3.2	Channel	0.5	Coarse sand	Sand	Young abandoned channel (sandbars from 1991 flood)
	c2a,b,c	1.1	6123	11.8	Channel	0.5	Coarse sand	Gravelly sand	Inset abandoned channels (active in 1980s, abandoned before 1991)
	c3	1.5	276	0.5	Channel	0.5	Coarse sand	Sand	Inset abandoned channel (active in 1981, abandoned before 1986)
	c4a	1.9	8064	15.5	Channel	2.5	Coarse sand	Sand	Abandoned channel (active ~1965, abandoned before 1974?)
	c4b	2.2	3791	7.3	Channel	2.4	Coarse sand	Gravelly sand	Abandoned channel (active ~1960, abandoned before 1965)
	c4b,c5				Overbank	0.1	Fine sand	Sandy loam	
	c5	2.8	4296	8.3	Channel	2.4	Coarse sand	Sand	Abandoned channel (active in 1950s, abandoned before 1960)
	c6	2	4897	9.4	Channel	0.8	Coarse sand	Sand	Abandoned channel (active in 1935, abandoned before 1954)
	c6				Overbank	0.2	Very fine sand	Sandy loam	
	f1	2.5	12,862	24.7	Overbank	0.05	Coarse silt	Sandy loam	Active floodplain
	f1a	2.2	5744	11.0	Overbank	0.15	Coarse silt	Loam	Floodplain with sediment dominated from canyon-wall drainages
	f2	3.2	5220	10.0	Overbank	<0.05	Fine sand	Sandy loam	Potentially active floodplain

*Average unit width uses lengths of 520 m for P-4 West and 600 m for P-4 East

TABLE 2.3-4 (continued)

GEOMORPHIC MAPPING UNITS IN REACH P-4

Subreach	Unit(s)	Estimated Average Unit Height (m)	Unit Area (m^2)	Average Unit Width* (m)	Sediment Facies	Estimated Average Thickness (m)	Typical Median Particle Size Class (<2 mm fraction)	Typical Soil Texture	Notes
P-4 East	c1	0	10047	16.7	Channel	0.5	Coarse sand	Gravelly sand	Active channel in 1991
	c1–c3				Overbank	0.05	Very fine sand	Sandy loam	
	c1b	0.4	4107	6.8	Channel	0.5	Coarse sand	Sand	Young abandoned channel (sandbars from 1991 flood)
P-4 East	c2a,b,c	0.8	1357	2.3	Channel	0.5	Coarse sand	Gravelly sand	Inset abandoned channels (active in 1980s, abandoned before 1991)
	c3	2.4	13,159	21.9	Channel	2.2	Coarse sand	Gravelly sand	Abandoned channel (active in 1981, abandoned before 1986)
	f1	1.4	31,750	52.9	Overbank	0.1	Coarse silt	Sandy loam	Active floodplain
					Channel	0.05	Coarse sand	Sand	
	f2	1.7	15,038	25.1	Overbank	<0.05	Fine sand	Sandy loam	Potentially active floodplain

*Average unit width uses lengths of 520 m for P-4 West and 600 m for P-4 East

2.3.4.3 Geomorphic History

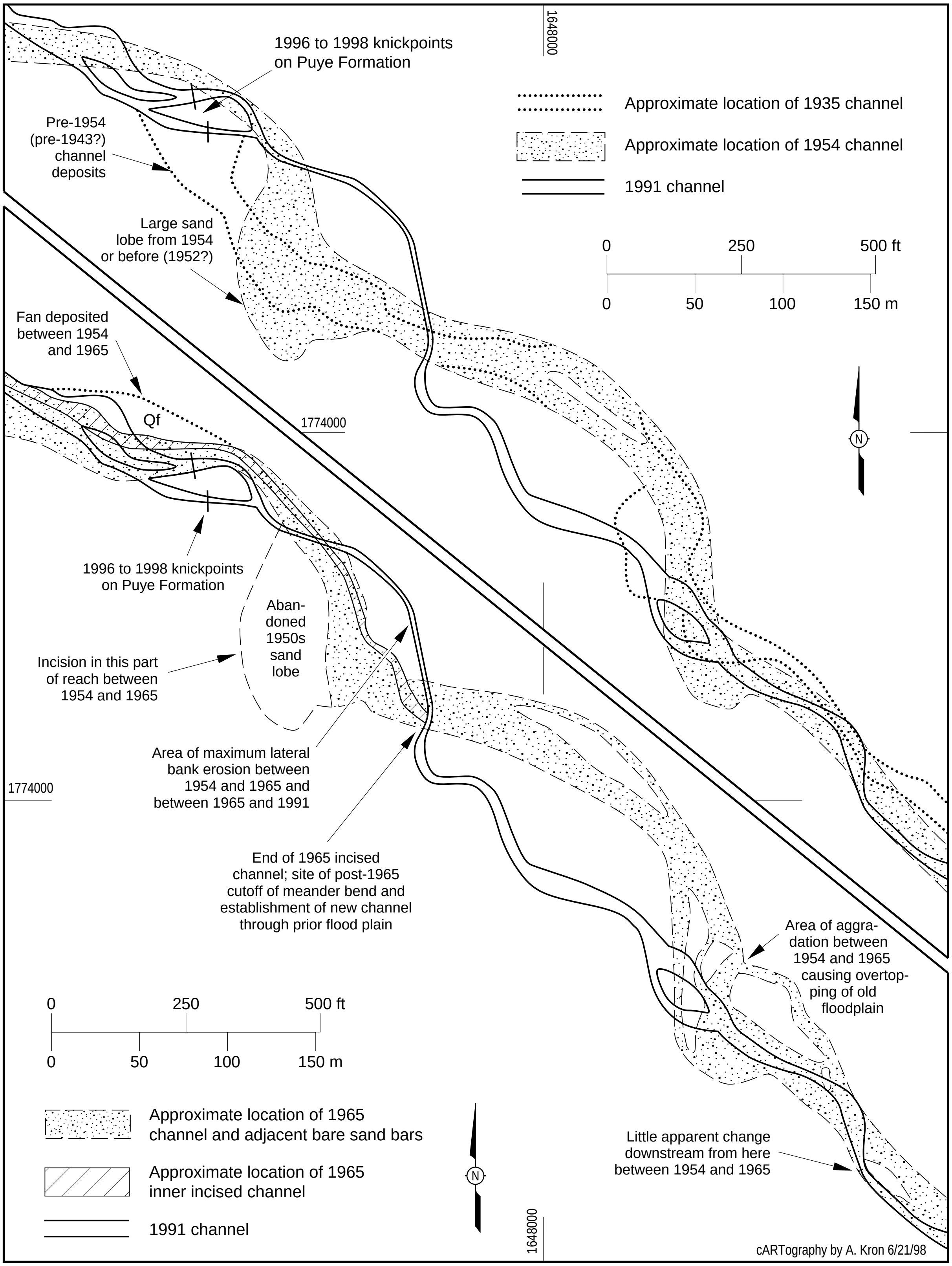
Major channel changes have occurred in reach P-4 since 1935 and have resulted in great spatial variability in the distribution and characteristics of the geomorphic units (Figures 2.3-21 and 2.3-22). Because contaminant concentrations in both channel and overbank sediments have varied through this time period, contaminant concentrations have significant spatial variability dependent on the age and particle size distribution of the sediments in each geomorphic unit.

Since 1935, the channel along P-4 first aggraded through deposition of bedload sediments that were dominated by coarse sand (raising the elevation of the stream bed) and then incised. The timing of maximum aggradation and subsequent incision varied from west to east, occurring progressively later to the east. Maximum aggradation at the west end of P-4 occurred in the 1950s, with incision having begun by 1960. Maximum aggradation and the beginning of subsequent incision in the east part of P-4 occurred between 1981 and 1986. Because of these spatial and temporal changes, the thickest and most extensive channel deposits in the west part of P-4 date to the 1960s and earlier and have relatively high levels of plutonium. In contrast, at least the upper part of the most widespread unit in the east part of P-4 was probably deposited in the late 1970s and the early 1980s and has lower levels of plutonium, although older sediments are probably buried at depth. The aggradation resulted in the deposition of exceptionally large volumes of coarse sand and associated gravels in P-4, much larger than in reaches to the west.

The age of historic overbank deposits probably also varies from west to east in P-4, resulting in variations in contaminant levels in sediments with similar particle size characteristics. The most widespread deposition of overbank sediments likely occurred contemporaneous with maximum aggradation, dating to the 1960s and earlier to the west and to the 1970s and early 1980s to the east. Exceptionally broad areas of P-4 East received overbank floodwaters in the 1970s, and most of the fine-grained overbank sediment on the f1 unit in this area was probably deposited during this period. After incision began in each part of P-4, the occurrence and extent of overbank flooding would have been restricted. The f1 units are presently too high above the active channel to be inundated during typical floods, and the abandoned channel units instead constitute the presently active floodplain in P-4.

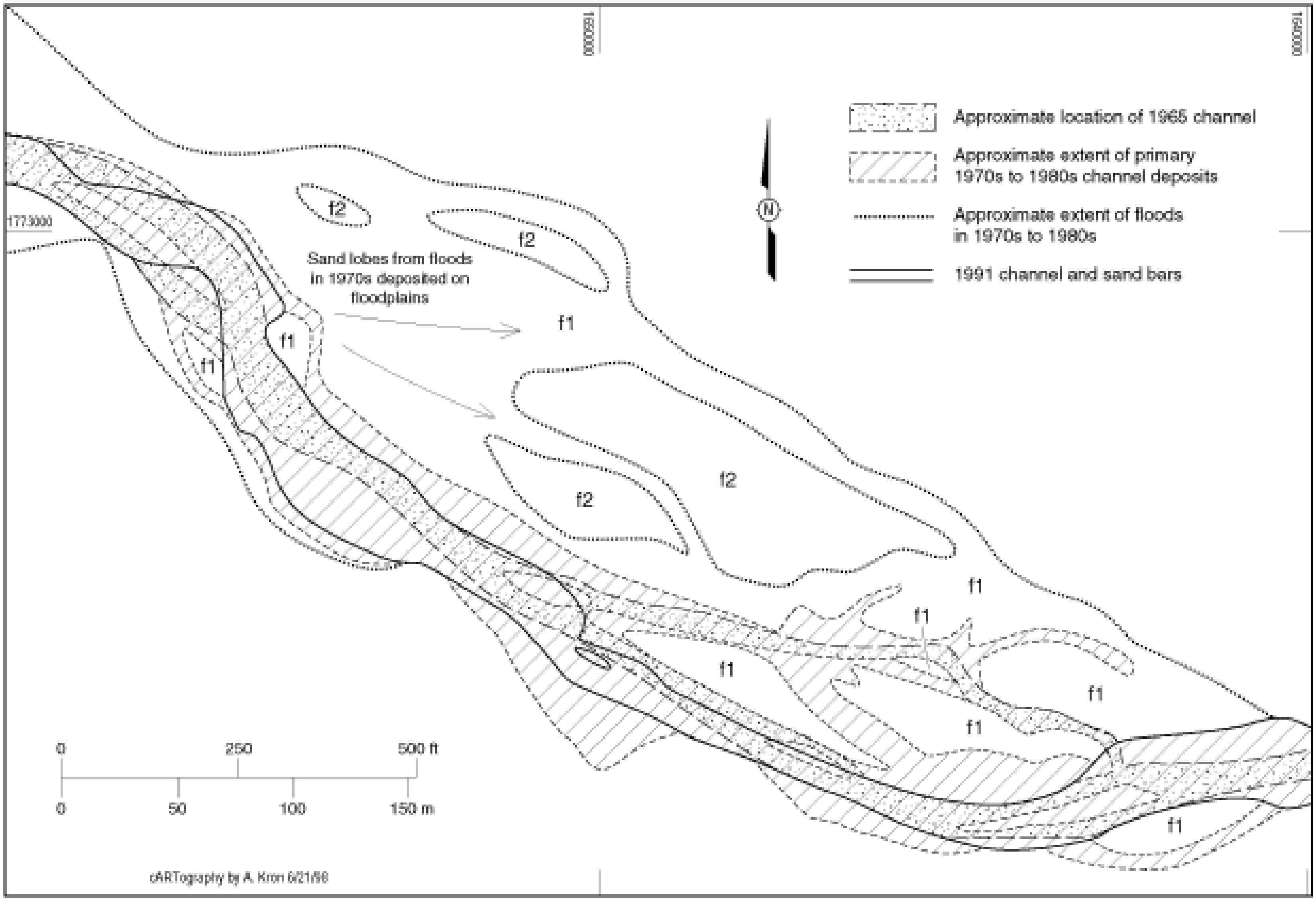
The most important geomorphic processes occurring in reach P-4 at present are lateral erosion of banks and some channel incision. This erosion probably constitutes a major source for the sediment that is transported out of Pueblo Canyon and into Los Alamos Canyon. Eroding banks include a combination of abandoned post-1935 channel units that largely contribute coarse sand with above background values of plutonium to the channel; f1 units, which contribute mostly pre-1943 sediment to the channel, along with lesser amounts of post-1942 overbank sediment; and pre-1943 material. Erosion of the f1 units and pre-1943 sediments would tend to dilute the plutonium in sediment carried during floods because only a small part of the height of these eroding banks is in post-1942 sediment. Incision of the channel bed also appears to still occur during floods, although this incision may be largely into pre-1943 sediment, which would also lead to the dilution of plutonium and the lowering of plutonium concentrations.

Bank erosion rates within P-4 are greatest at the outside of meander bends, and examination of historic aerial photographs indicates that up to 35 to 40 m of lateral erosion into floodplains and colluvial slopes has occurred in P-4 West since 1954 (Figure 2.3-21), providing maximum average bank erosion rates of approximately 1.0 m/yr. This lateral channel migration occurred during periods of both aggradation and subsequent degradation and has helped isolate large areas of contaminated c4a, c4b, and c5 deposits, such that these areas are not presently susceptible to remobilization. Progressive bank erosion at one location in P-4 West that occurred contemporaneous with channel aggradation also resulted in diversion of the active channel into a low part of the prior floodplain sometime after 1965 (Figure 2.3-21), an event that resulted in isolation of large areas of c4a and c4b and reduced the potential for remobilization of contaminated sediment in these areas.



F2.3-21 / PUEBLO CANYON REACH RPT / 082698

Figure 2.3-21. Channel changes in reach P-4 West as determined from historic aerial photographs showing overlays of the channel location in different years.



F2.3-22 / PUEBLO CANYON REACH RPT / 102398

Figure 2.3-22. Channel changes in reach P-4 East as determined from historical aerial photographs showing overlays of the channel location in different years.

Recent channel changes in P-4 East have also been effective at isolating much of the post-1942 sediment from the active channel. Between 1935 and 1981 a braided channel was present through the floodplains in the east half of this subreach, but the northern branch was abandoned before 1986 when major channel incision occurred, isolating large areas of c3 channel surfaces (Figure 2.3-22). Similarly, most of the area of f1 is north of and isolated from the active channel.

3.0 ANALYTICAL RESULTS AND DATA REVIEW

3.1 Data Review

Sediment samples collected in the Pueblo Canyon reaches included samples for full-suite, limited-suite, and key contaminant analyses. The samples were collected following the technical approach presented in Chapter 5 of the work plan (LANL 1995, 50290). Samples were collected to represent specific geomorphic units and sediment facies within each reach. The variability within and among these geomorphic units and sediment facies is a key variable to assess and will be considered in Sections 3.2 and 3.3. The number of samples varies among classes of analytes; the number of samples analyzed for organic chemicals, inorganic chemicals, and radionuclides is presented in Table 3.1-1. Full-suite analyses were obtained for 16 samples in reaches P-1 and P-4. The full-suite analytes included isotopic plutonium, polychlorinated biphenyls (PCBs) and pesticides, inorganic chemicals that are on the target analyte list (TAL), gamma-spectroscopy radionuclides (including americium-241 and cesium-137), semivolatile organic compounds (SVOCs), americium-241 by alpha spectroscopy, tritium, isotopic uranium, isotopic thorium, strontium-90, gross alpha/beta radiation, and gross gamma radiation. Volatile organic chemicals are excluded from the full suite analyses because these chemicals are not expected to persist in surface and near-surface sediments downstream from release sites. The following analytes were included in limited-suite analyses: (1) PCBs and pesticides for 30 samples and (2) inorganic chemicals that are on the TAL and gamma-spectroscopy radionuclides (including americium-241 and cesium-137) for 44 samples. Isotopic plutonium was chosen as a key contaminant in this investigation because the maximum plutonium-239,240 concentration measured approximately 7000 times the background value, and this radionuclide was shown by preliminary assessments to be the primary contributor to human health risk; isotopic plutonium was analyzed in 289 samples.

TABLE 3.1-1

NUMBER OF SAMPLES ANALYZED BY SUITE

Analytical Suite	Reach				
	P-1	P-2	P-3	P-4	Total
Pesticides and PCBs	7	6	8	9	30
SVOCs	7	0	0	9	16
Inorganic chemicals (TAL)	15	8	10	11	44
Boron, titanium, and total uranium	7	0	0	10	17
Total cyanide and uranium	7	0	0	9	16
Americium-241 (by alpha spectroscopy)	7	0	0	1	8
Gross alpha/beta radiation	7	0	0	9	16
Gross gamma radiation	7	0	0	9	16
Gamma-spectroscopy radionuclides	15	8	10	11	44
Tritium	7	0	0	9	16
Isotopic plutonium	64	79	64	82	289
Isotopic thorium	7	0	0	9	16
Isotopic uranium	7	0	0	9	16
Strontium-90	7	0	0	9	16

The objective of this data review is to determine which analytes should be retained for further assessment or eliminated before human health and ecological risk calculations. Considerations in these assessments include the magnitude of contaminant concentrations relative to background values (or detection limits for organic chemicals), the correlation between contaminant concentrations both between reaches and within reaches, and potential quality control (QC) problems with the laboratory analyses.

3.1.1 Inorganic Chemical Comparison with Background

Inorganic chemicals were analyzed in 44 sediment samples collected from all four Pueblo Canyon reaches. These analyses were compared with the sediment background values that are presented in “Inorganic and Radionuclide Background Data for Soils, Canyons Sediments, and Bandelier Tuff at LANL” (Ryti et al. 1998, 58093).

As detailed in Appendix C, most of the QC problems associated with this data set were caused by high or low recoveries in the matrix spike samples. Matrix spike samples are used to assess the quality of the sample digestion, extraction, and analysis procedures. A low recovery suggests that there was either incomplete recovery of an analyte in these procedures or sample heterogeneity. A high recovery indicates either sample heterogeneity or a matrix interference. One of the reasons for the repeated difficulties in the recoveries is the heterogeneous nature of many sediment samples. Also, for several of the analytes there are interferences in the inductively coupled plasma (ICP) technique, which can also cause problems with the reported recoveries. Specific data qualifications due to matrix spike recovery problems were noted for seven inorganic chemicals in a subset of the samples (aluminum, antimony, arsenic, lead, manganese, selenium, and titanium). Exceptionally low matrix spike recoveries were noted for antimony for some samples, and the remaining six inorganic chemicals had more minor deviations from the expected spike value. The low antimony matrix spike sample results caused antimony data from one sample request to be rejected (see Appendix C). Request number 1938 had nine antimony sample results, which were all “R” qualified and will not be used in this report.

Appendix C also shows other minor QC problems associated with detecting blank contamination, finding some laboratory duplicate measurements out of the ±35% control window and observing differences between ICP serial dilutions out of the 10% control window. The laboratory duplicate problems can be attributed to the heterogeneous nature of the sediment samples. Blank contamination is an indicator of possible high bias in the laboratory measurement process and could lead to incorrectly identifying chemicals as COPCs. However, these problems are not considered to be serious and should not affect the identification of COPCs.

The analytical methods for the inorganic chemicals are comparable to those used to generate the Laboratory background data, with the exception of antimony. Some of the Pueblo Canyon antimony data were generated by inductively coupled plasma emission spectroscopy (ICPES), which results in a detection limit above what is typically found in background soils. Because the Pueblo Canyon antimony data were generated by ICPES, the antimony detection limits for these samples are elevated above the background value (BV).

Because the Laboratory background data contain values for both “uranium” and “total uranium,” the uranium sample preparation and analysis methods must be reviewed to identify the appropriate uranium background data. Uranium was analyzed by inductively coupled plasma mass spectroscopy (ICPMS), which is comparable to the analytical methods used to generate the uranium and total uranium background data. These samples were prepared using both a total sample digest and by Environmental Protection Agency (EPA) method 3050A. The samples prepared by a total digest were compared with the total uranium sediment background data, and samples prepared with EPA method 3050A were compared with the uranium sediment background data.

Of 27 inorganic chemicals, 26 were detected in at least one Pueblo Canyon sediment sample. Antimony was not detected in any sample. The detection limit for most antimony sample results exceeded the background value. Detection limits for some of the cadmium, mercury, selenium, and silver analyses also exceed the background value. Tables 3.1-2, 3.1-3, 3.1-4, and 3.1-5 present the concentration range and frequency of results above the background value for the 26 detected inorganic chemicals and the one nondetected inorganic chemical.

Sodium was the only inorganic chemical measured above the detection limit but within the background range. Sodium will not be retained for further assessment in this report because it is not greater than sediment background concentrations.

The sample results for a number of inorganic chemicals are influenced by two notable samples collected in reach P-4. The first sample (04PU-96-0026) was collected from a channel facies sediment layer rich in black magnetite sands, which had provided a field alpha radiation measurement that was relatively high for P-4 East. The sample has detected concentrations of iron, manganese, thallium, titanium, and zinc above background values. Black magnetite-rich sands are naturally-occurring sediments produced by fluvial sorting and concentration of high-density minerals that are have elevated concentrations of several metals including iron, manganese, and zinc (Reneau et al. 1998, 62050; McDonald et al. 1996, 55532). Because concentrations of inorganic chemicals in this sample are consistent with those found in naturally-occurring black sands, inorganic results for the black magnetite-rich sand sample are not used to identify chemicals of potential concern (COPCs). The second sample (04PU-96-0030) was collected from an iron- and aluminum-rich overbank facies sediment layer in P-4 West. The sample has concentrations of aluminum, arsenic, barium, beryllium, calcium, chromium, cobalt, copper, iron, lead, magnesium, nickel, potassium, vanadium, and zinc above background values. As described in “Inorganic and Radionuclide Background Data for Soils, Canyons Sediments, and Bandelier Tuff at LANL” (Ryti et al. 1998, 58093), iron- and aluminum-rich deposits tend to have high concentrations of other inorganic chemicals, and concentrations in sample 04PU-96-0030 are consistent with relationships present in background samples. Plots showing these relationships are provided in Appendix E. Thus, the results for inorganic chemicals in sample 04PU-96-0030 are considered to be within the natural background concentration range for an iron- and aluminum-rich sediment deposit. This sample is from a location where much of the fine-grained sediment was probably derived from erosion of old soils on the south side of Pueblo Canyon, associated with the f1a unit (sample location PU-0037, Figure 2.3-17), and the unusually high iron and aluminum concentrations are believed to have been inherited from the original soils.

Statistical and graphical data evaluation approaches were applied to the inorganic chemical data, which included consideration of samples 04PU-96-0026 and 04PU-96-0030 as representative of natural background material for the reasons discussed above. This evaluation led to the elimination of the following 17 inorganic chemicals that were not significantly different from background from further assessment: aluminum, arsenic, barium, beryllium, boron, calcium, chromium, cyanide, iron, magnesium, manganese, nickel, potassium, thallium, titanium, uranium, and vanadium. Three of these analytes (arsenic, manganese, and titanium) had QC problems associated with matrix spike samples. The samples with low matrix spike recoveries do not appear to differ from the expected background values or major element ratios (see Appendix E). Thus, QC problems did not lead to incorrectly eliminating these inorganic chemicals as COPCs. The statistical analyses and graphs that support this evaluation are provided in Appendix E.

TABLE 3.1-2

FREQUENCY OF DETECTED INORGANIC CHEMICALS IN REACH P-1

Analyte	Number of Samples Analyzed	Number of Detects	Concentration Range (mg/kg)[a]	Maximum Detect (mg/kg)	Background Value (mg/kg)	Frequency of Detects above Background Value[b]
Aluminum	15	15	2040 to 8850	8850	15400	0/15
Antimony	15	0	[0.72] to [4.9]	ND[c]	0.83	8 DL[d]>BV[e]
Arsenic	15	8	0.98 to [3.7]	2.7	3.98	0/8
Barium	15	15	36 to 94.4	94.4	127	0/15
Beryllium	15	15	0.19 to 0.93	0.93	1.31	0/15
Boron	7	5	[1.2] to 6.2	6.2	4.1	1/5
Cadmium	15	14	[0.09] to 0.92	0.92	0.4	5/14
Calcium	15	15	598 to 4740	4740	4420	1/15
Chromium, total	15	15	2.8 to 12.9	12.9	10.5	2/15
Cobalt	15	15	1.3 to 4.9	4.9	4.73	1/15
Copper	15	15	2.7 to 19.9	19.9	11.2	4/15
Cyanide, total	7	2	[0.15] to 0.45	0.45	0.723	0/2
Iron	15	15	6580 to 11600	11600	13800	0/15
Lead	15	15	8.5 to 77.3	77.3	19.7	13/15
Magnesium	15	15	385 to 1180	1180	2370	0/15
Manganese	15	15	202 to 529	529	543	0/15
Mercury	15	14	[0.02] to 0.65	0.65	0.1	9/14
Nickel	15	15	1 to 6.2	6.2	9.38	0/15
Potassium	15	15	370 to 1700	1700	2690	0/15
Selenium	15	3	0.3 to [1.1]	0.62	0.3	3/3, 12/12 DL>BV
Silver	15	8	[0.1] to 1.7	1.7	1	3/8
Sodium	15	15	36.6 to 786	786	1470	0/15
Thallium	15	0	[0.4] to [0.59]	ND	0.73	0/0
Titanium	7	7	224 to 368	368	439	0/7
Uranium	7	7	0.26 to 3.1	3.1	2.22	2/7
Uranium, total	7	7	2.1 to 6.5	6.5	6.99	0/7
Vanadium	15	15	7.9 to 17.4	17.4	19.7	0/15
Zinc	15	15	27.8 to 113	113	60.2	7/15

a. Values in square brackets indicate nondetected results.

b Value is the ratio of the number of detected values exceeding the background value to the number of analyses.

c. ND = not detected

d. DL = detection limit

e. BV = background value

TABLE 3.1-3

FREQUENCY OF DETECTED INORGANIC CHEMICALS IN REACH P-2

Analyte	Number of Samples Analyzed	Number of Detects	Concentration Range (mg/kg)[a]	Maximum Detect (mg/kg)	Background Value (mg/kg)	Frequency of Detects above Background Value[b]
Aluminum	8	8	881 to 4760	4760	15400	0/8
Antimony	8	0	[0.5] to [0.6]	ND[c]	0.83	0/0
Arsenic	8	6	[1] to 2.6	2.6	3.98	0/6
Barium	8	8	15.3 to 89.1	89.1	127	0/8
Beryllium	8	4	[0.5] to 0.76	0.76	1.31	0/4
Cadmium	8	0	[0.5] to [0.6]	ND	0.4	8/8 DL[d]>BV[e]
Calcium	8	8	372 to 3560	3560	4420	0/8
Chromium, total	8	8	1.3 to 5.7	5.7	10.5	0/8
Cobalt	8	8	1.3 to 3.3	3.3	4.73	0/8
Copper	8	8	3.9 to 31.5	31.5	11.2	1/8
Iron	8	8	5840 to 8200	8200	13800	0/8
Lead	8	8	6.4 to 27.7	27.7	19.7	2/8
Magnesium	8	8	221 to 1200	1200	2370	0/8
Manganese	8	8	103 to 344	344	543	0/8
Mercury	8	2	[0.1] to 0.15	0.15	0.1	2/2, 4/6 DL>BV
Nickel	8	5	[2.1] to 5	5	9.38	0/5
Potassium	8	8	238 to 1270	1270	2690	0/8
Selenium	8	7	0.5 to 0.98	0.98	0.3	7/7, 1/1 DL>BV
Silver	8	0	[1] to [1.2]	ND	1	5/8 DL>BV
Sodium	8	3	[100] to 356	356	1470	0/3
Thallium	8	0	[1] to [1.2]	ND	0.73	8/8 DL>BV
Vanadium	8	8	5.5 to 11.7	11.7	19.7	0/8
Zinc	8	8	27.7 to 54.1	54.1	60.2	0/8

a. Values in square brackets indicate nondetected results.
b Value is the ratio of the number of detected values exceeding the background value to the number of analyses.
c. ND = not detected
d. DL = detection limit
e. BV = background value

TABLE 3.1-4

FREQUENCY OF DETECTED INORGANIC CHEMICALS IN REACH P-3

Analyte	Number of Samples Analyzed	Number of Detects	Concentration Range (mg/kg)[a]	Maximum Detect (mg/kg)	Background Value (mg/kg)	Frequency of Detects above Background Value[b]
Aluminum	10	10	1060 to 3760	3760	15400	0/10
Antimony	10	0	[0.5] to [0.69]	ND[c]	0.83	0/0
Arsenic	10	5	[1] to 1.7	1.7	3.98	0/5
Barium	10	10	16.3 to 52.8	52.8	127	0/10
Beryllium	10	5	[0.5] to 0.81	0.81	1.31	0/5
Cadmium	10	0	[0.5] to [0.69]	ND	0.4	10/10 DL[d]>BV[e]
Calcium	10	10	327 to 1250	1250	4420	0/1
Chromium, total	10	10	1.1 to 3.7	3.7	10.5	0/10
Cobalt	10	8	[1] to 2.5	2.5	4.73	0/8
Copper	10	10	2 to 20.5	20.5	11.2	1/10
Iron	10	10	3170 to 7570	7570	13800	0/10
Lead	10	10	3.7 to 14.2	14.2	19.7	0/10
Magnesium	10	10	220 to 781	781	2370	0/10
Manganese	10	10	156 to 247	247	543	0/10
Mercury	10	0	[0.1] to [0.14]	ND	0.1	8/10 DL>BV
Nickel	10	5	[2] to 4	4	9.38	0/5
Potassium	10	10	272 to 959	959	2690	0/10
Selenium	10	3	[0.5] to 0.69	0.69	0.3	3/3, 7/7 DL>BV
Silver	10	0	[1] to [1.4]	ND	1	8/10 DL>BV
Sodium	10	1	[100] to 147	147	1470	0/10
Thallium	10	0	[1] to [1.4]	ND	0.73	10/10 DL>BV
Vanadium	10	10	3.4 to 9	9	19.7	0/10
Zinc	10	10	15.8 to 39.3	39.3	60.2	0/10

a. Values in square brackets indicate nondetected results.

b Value is the ratio of the number of detected values exceeding the background value to the number of analyses.

c. ND = not detected

d. DL = detection limit

e. BV = background value

TABLE 3.1-5

FREQUENCY OF DETECTED INORGANIC CHEMICALS IN REACH P-4

Analyte	Number of Samples Analyzed	Number of Detects	Concentration Range (mg/kg)[a]	Maximum Detect (mg/kg)	Background Value (mg/kg)	Frequency of Detects above Background Value[b]
Aluminum	11	11	1330 to 18400	18400	15400	1/11
Antimony[c] (1)	2	0	[0.5] to [4.3]	ND[d]	0.83	1/2[c] DL[e]>BV[f]
Arsenic	11	3	0.779 to 5.1	5.1	3.98	1/3
Barium	11	11	14.9 to 163	163	127	1/11
Beryllium	11	11	0.16 to 1.7	1.7	1.31	1/11
Boron	10	0	[1.2] to [5.5]	ND	4.1	2/10 DL>BV
Cadmium	11	3	[0.2] to 0.52	0.52	0.4	3/3, 1/8 DL>BV
Calcium	11	11	412 to 4610	4610	4420	1/11
Chromium, total	11	11	2.88 to 14.5	14.5	10.5	1/11
Cobalt	11	11	0.85 to 5.6	5.6	4.73	1/11
Copper	11	11	1 to 12.8	12.8	11.2	1/11
Cyanide, total	9	6	[0.15] to 1	1	0.723	1/6
Iron	11	11	4440 to 36600	36600 15400[g]	13800	2/11
Lead	11	11	5.6 to 30.5	30.5	19.7	2/11
Magnesium	11	11	318 to 3050	3050	2370	1/11
Manganese	11	11	157 to 1030	1030 484[g]	543	1/11
Mercury	11	4	0.02 to 0.11	0.11	0.1	1/4
Nickel	11	11	2.3 to 11	11	9.38	1/11
Potassium	11	11	462 to 3740	3740	2690	1/11
Selenium	11	0	[0.2] to [0.5]	ND	0.3	1/11 DL>BV
Silver	11	6	[0.1] to 1	1	1	0/6
Sodium	11	10	88.8 to 1440	1440	1470	0/10
Thallium	11	1	[0.18] to 6.7	6.7 ND[g]	0.73	1/1, 7/10 DL>BV
Titanium	10	10	0.454 to 1840	1840 349[g]	439	1/10
Uranium	9	9	0.33 to 1.7	1.7	2.22	0/9
Uranium, total	10	8	[2.2] to 5.9	5.9	6.99	0/8
Vanadium	11	11	5.1 to 23.8	23.8 20.3[g]	19.7	2/11
Zinc	11	11	24.3 to 222	222 66.9[g]	60.2	3/11

a. Values in square brackets indicate nondetected results.

b Value is the ratio of the number of detected values exceeding the background value to the number of analyses.

c. Nine sample results from request number 1938 were rejected and are not presented in this table.

d. ND = not detected

e. DL = detection limit

f. BV = background value

g. Maximum value for this analyte after excluding the black magnetite sands (sample 04PU-96-0026)

One inorganic chemical, antimony, was not detected in any sample, but several samples had detection limits above the background value. Antimony is retained as a COPC solely because of the elevated detection limits for these samples. Antimony also had serious QC problems, which need to be considered during site assessments. The QC problems did not lead to the elimination of antimony as a COPC, thus no more discussion of antimony is warranted in this data review section.

Seven other inorganic chemicals were shown to be elevated above background values by a statistical and graphical background comparison and are retained as COPCs. The statistical analyses and graphs that support this evaluation are provided in Appendix E. These inorganics included cadmium, copper, lead, mercury, selenium, silver, and zinc. There were minor QC problems (small differences from expected values for matrix spike recovery, laboratory duplicate results, or ICP serial dilutions, see Appendix C for details) associated with lead, but these problems are not viewed to be significant and are not expected to impact data review. There were also minor QC problems of a similar nature associated with selenium. It is also important to recognize that all of the apparently elevated selenium results are derived from two of the five analytical laboratories used for inorganic chemical analyses, and potential problems are recognized with selenium analyses from these laboratories. One sample request from reach P-1 with elevated selenium results was analyzed at the Rust Geotech analytical laboratory. However, these samples were also submitted under a separate sample request to the QST Environmental analytical laboratory for organic chemical analyses. QST Environmental mistakenly ran the samples for inorganic chemical analyses, and the QST Environmental selenium results were all nondetects (at values less than the background value). Four other sample requests with elevated selenium results, including all the inorganic chemical analyses for reaches P-2 and P-3, were analyzed at the Paragon Analytics, Inc. analytical laboratory. The lowest value reported by Paragon Analytics, Inc. was approximately two times the background value. Therefore, the selenium sample results should be interpreted carefully in terms of both variation in detection limits and potential interlaboratory differences in specific sample preparation or analytical methods. However, because there is no specific information to document analytical laboratory bias, selenium is retained as a COPC.

In summary, the inorganic chemical data review yielded eight analytes to be carried forward as COPCs (see Table 3.1-6). A complete presentation of the sample results for these eight inorganic COPCs is provided in Appendix D-4.0. These analytes are inferred to potentially record releases from one or more sites in the Pueblo Canyon watershed. The concentrations of the chemicals eliminated as COPCs were well within the background concentration range, except for the two P-4 samples discussed previously, and are justifiably excluded from further assessment.

3.1.2 Radionuclide Comparison with Background/Fallout Radionuclide Concentrations

A total of 299 samples were analyzed for radionuclides in the four Pueblo Canyon reaches, and the analytical suites for these samples are presented in Table 3.1-1. These analyses were compared with the sediment background values that are presented in “Inorganic and Radionuclide Background Data for Soils, Canyons Sediments, and Bandelier Tuff at LANL” (Ryti et al. 1998, 58093). The analytical methods used for the Pueblo Canyon radionuclide analyses are comparable to those used with the Laboratory background data.

The detected radionuclides include isotopes associated with worldwide fallout. For these radionuclides (tritium, strontium-90, cesium-137, plutonium-238, and plutonium-239,240) only sample results collected from the 0 to 15-cm (0 to 6-in.) depth interval are typically compared with regional levels for worldwide fallout in soil samples. However, post-1942 sediment deposits containing fallout-derived radionuclides can be much thicker than 15 cm, and all sediment sample results in this investigation, regardless of collection depth, are compared with the sediment background value.

TABLE 3.1-6

RESULTS OF INORGANIC DATA REVIEW

Analyte	Result	Rationale
Aluminum	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Antimony	Retained as a COPC	Detection limits in reaches P-1 and P-4 exceeded the background value.
Arsenic	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Barium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Beryllium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Boron	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Cadmium	Retained as a COPC	Detected values above the background value in reaches P-1 and P-4 and detection limits above the background value in reaches P-2 and P-3.
Calcium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Chromium, total	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Cobalt	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Copper	Retained as a COPC	Detected values in reaches P-1, P-2 and P-3.
Cyanide, total	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Iron	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Lead	Retained as a COPC	Detected values above the background value in reaches P-1 and P-2.
Magnesium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Manganese	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Mercury	Retained as a COPC	Detected values above the background value in reaches P-1, P-2, and P-4 and detection limits above the background value in reach P-3.
Nickel	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Potassium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Selenium	Retained as a COPC	Detected values above the background value in reaches P-1, P-2, and P-3 and detection limits above the background value in reach P-4.
Silver	Retained as a COPC	Detected values above the background value in reach P-1 and detection limits above the background value in reaches P-2, P-3, and P-4.
Sodium	Eliminated as a COPC	No values exceeded the background value.
Thallium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Titanium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Uranium and total uranium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Vanadium	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Zinc	Retained as a COPC	Detected values above the background value in reach P-1.

As described in Appendix C, detection status was determined by either quantitation limits agreed upon in contracts with the analytical laboratories, minimum detectable activities determined by the analytical laboratories, or the 3 sigma total propagated uncertainty (TPU). Detection status was used as the preliminary data evaluation step for isotopic uranium by alpha spectroscopy, isotopic thorium by alpha spectroscopy, americium-241 by alpha spectroscopy, and strontium-90 by beta scintillation. Gamma spectroscopy yields 43 radionuclides, which requires an additional evaluation of the detected radionuclides to determine which gamma-spectroscopy results should be carried forward for background comparisons.

The initial list of detected radionuclides from gamma spectroscopy include actinium-228, americium-241, bismuth-211, bismuth-212, bismuth-214, cadmium-109, cerium-139, cesium-137, europium-152, lanthanum-140, lead-212, lead-214, manganese-54, potassium-40, protactinium-231, radium-224, radium-226, thallium-208, and thorium-234 (see Appendix D-3.0 for a summary of the number of samples and range of detected and nondetected concentrations for all radionuclides). These detected gamma-spectroscopy radionuclides fall into five categories.

- The first category includes radionuclides that are daughters of naturally-occurring thorium and uranium isotopes (these include actinium-228 [half-life = 6.2 hours], bismuth-211 [half-life = 2.1 minutes], bismuth-212 [half-life = 7 minutes], bismuth-214 [half-life = 20 minutes], lead-212 [half-life = 10.6 hours], lead-214 [half-life = 27 minutes], protactinium-231 [half-life = 33,000 years], radium-224 [half-life = 3.7 days], radium-226 [half-life = 1,600 years], thallium-208 [half-life = 3.1 minutes], and thorium-234 [half-life = 24 days]). These thorium and uranium daughters are typically short-lived radiological decay products, and their abundance can be predicted from the general condition known as secular equilibrium (Ryti et al. 1998, 58093). Most of the radiological dose conversion factors used in risk assessments of the parent radionuclides account for the expected activity of the daughter radionuclides. Thus, these detected thorium and uranium daughters are of no further interest for this report.

- The second category includes potassium-40, which is a naturally-occurring isotope that is abundant in the Earth's crust and is not known to be associated with Laboratory releases. Thus, potassium-40 will not receive any further evaluation in this report.

- The third category includes nuclear reactor activation or fission products with half-lives of less than one year, which includes manganese-54 (half-life = 312 days). Because of the short half-life and low detected concentrations of this radionuclide (see Appendix D-3.0 for concentration range), manganese-54 is excluded from further evaluation.

- The fourth category includes cadmium-109 (half-life = 462 days), which is used an analytical laboratory control standard and does not warrant further evaluation in this report.

- The last group consists of plutonium chemistry or nuclear reactor activation or fission products with half-lives of greater than one year, which includes americium-241 (half-life = 430 years), cesium-137 (half-life = 30 years), and europium-152 (half-life = 13.5 years) for the Pueblo Canyon gamma-spectroscopy data. Because there is no process knowledge to associate europium-152 with releases into Pueblo Canyon, it is excluded from further data evaluation. Americium-241 and cesium-137 will be carried forward to the background comparison because previous investigations have identified these radionuclides as being released into Pueblo Canyon.

Thus, cesium-137 and americium-241 are the only gamma-spectroscopy radionuclides carried forward to the background comparison. Seventeen other detected gamma-spectroscopy radionuclides were eliminated for the reasons presented above.

As discussed in Appendix C, most of the QC problems associated with the radionuclide analyses are considered to be minor and do not affect the identification of COPCs. For example, some measures of laboratory measurement bias were outside of control windows for a small number of samples. Tracer recoveries for americium-241 in two samples and the matrix spike sample results for uranium-235 for one request were outside of the acceptable control window. Laboratory precision for the radionuclide analyses was within control standards except for a single laboratory duplicate analysis for uranium-234. The overall quality and comparability of the radionuclide data are also evident through the detailed statistical analyses in Appendix E. For example, Appendix E shows the strong correlation of the results for radionuclides in the uranium and thorium decay chains, which is consistent with the hypothesis of secular equilibrium (Ryti et al. 1998, 58093).

Eleven radionuclides were detected in the sediment samples. Tables 3.1-7, 3.1-8, 3.1-9, and 3.1-10 present the concentration range and frequency of results above the background value for these radionuclides.

Five detected radionuclides, including thorium-228, thorium-230, thorium-232, uranium-234, and uranium-238, were eliminated as COPCs because concentrations of these radionuclides were not above background values and show no statistical differences from background The graphical and statistical background comparisons for these radionuclides can be found in Appendix E. Six detected radionuclides, including americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90; and tritium were retained as COPCs based on the statistical and graphical background comparisons presented in Appendix E.

TABLE 3.1-7

FREQUENCY OF DETECTED RADIONUCLIDES IN REACH P-1

Analyte	Number of Analyses	Number of Detects	Concentration Range (pCi/g)[a]	Background Value/ Fallout Value (pCi/g)	Frequency of Detects above Background Value/Fallout Value
Americium-241	7	6	[0.016] to 10.671	0.04	6 of 6
Americium-241[b]	15	9	[0.012] to 11.48	DL[c]	9 of 9
Cesium-137	15	9	[0.001] to 1.53	0.9	1 of 9
Plutonium-238	64	49	[-0.017] to 2.078	0.006	49 of 49
Plutonium-239,240	64	64	0.039 to 502.01	0.068	61 of 64
Strontium-90	7	3	[0.36] to 1.4	1.04	1 of 3
Thorium-228	7	7	0.74 to 1.71	2.28	0 of 7
Thorium-230	7	7	0.66 to 1.44	2.29	0 of 7
Thorium-232	7	7	0.76 to 1.55	2.33	0 of 7
Tritium	7	7	0.021 to 1.21	0.093	2 of 7
Uranium-234	7	7	0.64 to 2.4	2.59	0 of 7
Uranium-238	7	7	0.69 to 2.2	2.29	0 of 7

a. Values in square brackets indicate nondetected results.
b By gamma spectroscopy
c. DL = sample-specific detection limit (see Appendix D, Table D3-2 for nondetect concentration range)

TABLE 3.1-8

FREQUENCY OF DETECTED RADIONUCLIDES IN REACH P-2

Analyte	Number of Analyses	Number of Detects	Concentration Range (pCi/g)[a]	Background Value/ Fallout Value (pCi/g)	Frequency of Detects above Background Value/Fallout Value
Americium-241[b]	8	1	[-0.115] to 1.199	DL[c]	1 of 1
Cesium-137	8	3	[0.0151] to 0.5612	0.9	0 of 3
Plutonium-238	79	21	[-0.014] to 0.231	0.006	21 of 21
Plutonium-239,240	79	77	[0.001] to 73.4	0.068	76 of 77

a. Values in square brackets indicate nondetected results.

b By gamma spectroscopy

c. DL = sample-specific detection limit (see Appendix D, Table D3-2 for nondetect concentration range)

TABLE 3.1-9

FREQUENCY OF DETECTED RADIONUCLIDES IN REACH P-3

Analyte	Number of Analyses	Number of Detects	Concentration Range (pCi/g)[a]	Background Value/ Fallout Value (pCi/g)	Frequency of Detects above Background Value/Fallout Value
Americium-241[b]	10	1	[-0.069] to [0.972]	DL[c]	1 of 1
Cesium-137	10	4	[0] to 0.68	0.9	0 of 4
Plutonium-238	64	7	[-0.0052] to 0.136	0.006	7 of 7
Plutonium-239,240	64	64	[0.0055] to 44.9	0.068	59 of 64

a. Values in square brackets indicate nondetected results.

b By gamma spectroscopy

c. DL = sample-specific detection limit (see Appendix D, Table D3-2 for nondetect concentration range)

TABLE 3.1-10

FREQUENCY OF DETECTED RADIONUCLIDES IN REACH P-4

Analyte	Number of Analyses	Number of Detects	Concentration Range (pCi/g)[a]	Background Value/ Fallout Value (pCi/g)	Frequency of Detects above Background Value/Fallout Value
Americium-241	10	9	0.047 to 0.92	0.04	9 of 9
Americium-241[b]	11	11	0.11 to 2.077	DL[c]	11 of 11
Cesium-137	11	5	[-0.1207] to 0.89	0.9	0 of 5
Plutonium-238	82	22	[-0.0102] to 0.62	0.006	22 of 22
Plutonium-239,240	82	81	[0.024] to 170.5	0.068	78 of 81
Thorium-228	9	9	0.79 to 2.04	2.28	0 of 9
Thorium-230	9	9	0.8 to 2.03	2.29	0 of 9
Thorium-232	9	9	0.78 to 2.01	2.33	0 of 9
Tritium	9	9	0.003 to 0.117	0.093	1 of 9
Uranium-234	9	9	0.83 to 1.9	2.59	0 of 9
Uranium-238	9	9	0.72 to 2	2.29	0 of 9

a. Values in square brackets indicate nondetected results.

b By gamma spectroscopy

c. DL = sample-specific detection limit (see Appendix D, Table D3-2 for nondetect concentration range)

In summary, the radionuclide data review yielded six analytes to be carried forward as COPCs (see Table 3.1-11). A complete presentation of the sample results for these COPCs is provided in Section 3.3 or Appendix D-4.0. Both background values and knowledge of the radionuclide releases into Pueblo Canyon were used to eliminate radionuclides as COPCs.

TABLE 3.1-11

RESULTS OF RADIONUCLIDE DATA REVIEW

Analyte	Result	Rationale
Americium-241	Retained as a COPC	Values were determined to be above background in reaches P-1, P-2, P-3, and P-4.
Cesium-137	Retained as a COPC	Values were determined to be above background in reach P-1.
Plutonium-238	Retained as a COPC	Values were determined to be above background in reaches P-1, P-2, P-3, and P-4.
Plutonium-239,240	Retained as a COPC	Values were determined to be above background in reaches P-1, P-2, P-3, and P-4.
Strontium-90	Retained as a COPC	Values were determined to be above background in reach P-1.
Thorium-228	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Thorium-230	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Thorium-232	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Tritium	Retained as a COPC	Values were determined to be above background in reach P-1, and tritium was not in the analytical suite for reaches P-2 and P-3.
Uranium-234	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.
Uranium-238	Eliminated as a COPC	Statistical and graphical methods as presented in Appendix E.

3.1.3 Evaluation of Organic Chemicals

Thirty sediment samples were analyzed for PCBs and pesticides. Sixteen sediment samples were analyzed for SVOCs. Twenty-nine organic chemicals were detected in these samples.

As presented in Appendix C, QC problems associated with the organic analyses are limited to a select number of analytes and samples. The only significant QC problems regarding COPC identification relates to the nondetection status of one SVOC (n-nitroso-di-n-propylamine) and two pesticides (δ-BHC and endrin). A focused data validation suggests that these chemicals were not detected; thus, they will not be retained for data assessment.

As noted in Appendix C, many of the reported detected SVOCs are less than the estimated quantitation limit (EQL). The greater sensitivity of the analytical method (lower detection limit) for some samples reflects differences in potential interferences from the matrix or absence of other organic chemicals. All organic chemicals that were detected in at least one sample are retained for further assessment, regardless of whether such reported detections are less than the EQL.

Tables 3.1-12, 3.1-13, 3.1-14, and 3.1-15 present the concentration range and frequency of detects for these analytes. A complete presentation of the sample results for the organic COPCs can be found in Appendix D.

TABLE 3.1-12

FREQUENCY OF DETECTED ORGANIC CHEMICALS IN REACH P-1

Analyte	Number of Analyses	Number of Detects	EQL (mg/kg)	Range of Concentrations (mg/kg)[a]	Maximum Detect (mg/kg)	Frequency of Detects
Aroclor-1254	7	1	0.033	[0.0134] to 0.238	0.238	1/7
Aroclor-1260	7	4	0.033	[0.0134] to 0.117	0.117	4/7
Aldrin	7	3	0.033	[0.00067] to 0.00211	0.00211	3/7
δ-BHC	7	1	0.033	[0.00067] to 0.00197	0.00197	1/7
α-Chlordane	7	4	0.0165	[0.00067] to 0.00497	0.00497	4/7
γ-Chlordane	7	1	0.0165	[0.00067] to 0.00211	0.00211	1/7
4,4'-DDT	7	3	0.033	[0.00067] to 0.00599	0.00599	3/7
Acenaphthene	7	3	0.33	0.055 to [0.34]	0.17	3/7
Acenaphthylene	7	1	0.33	[0.33] to [0.66]	0.44	1/7
Anthracene	7	5	0.33	0.039 to [0.34]	0.3	5/7
Benz(a)anthracene	7	5	0.33	0.079 to 1	1	5/7
Benzo(a)pyrene	7	6	0.33	0.052 to 1.7	1.7	6/7
Benzo(b)fluoranthene	7	6	0.33	0.07 to 2.5	2.5	6/7
Benzo(g,h,i)perylene	7	4	0.33	0.076 to 0.86	0.86	4/7
Benzo(k)fluoranthene	7	5	0.33	0.059 to 0.95	0.95	5/7
Benzoic acid	7	6	0.33	0.042 to [3.3]	0.75	6/7
Bis(2-ethylhexyl)phthalate	7	1	0.33	[0.074] to 2.8	2.8	1/7
Carbazole	7	4	0.33	0.052 to [0.34]	0.18	4/7
Chrysene	7	6	0.33	0.056 to 1.2	1.2	6/7
Di-n-octylphthalate	7	1	0.33	[0.33] to 0.66	ND[b]	1/7
Dibenz(a,h)anthracene	7	2	0.33	0.069 to [0.66]	0.28	2/7
Dibenzofuran	7	3	0.33	0.064 to [0.34]	0.097	3/7
Fluoranthene	7	6	0.33	0.093 to 1.9	1.9	6/7
Fluorene	7	4	0.33	0.046 to [0.34]	0.18	4/7
Indeno(1,2,3-cd)pyrene	7	4	0.33	0.086 to 0.88	0.88	4/7
2-Methylnaphthalene	7	2	0.33	0.038 to [0.66]	0.074	2/7
Naphthalene	7	4	0.33	0.035 to [0.34]	0.2	4/7
Phenanthrene	7	6	0.33	0.064 to 1.2	1.2	6/7
Pyrene	7	6	0.33	0.08 to 2.2	2.2	6/7

a. Values in square brackets indicate nondetected results.

b. ND = not detected

TABLE 3.1-13

FREQUENCY OF DETECTED ORGANIC CHEMICALS IN REACH P-2

Analyte	Number of Analyses	Number of Detects	EQL (mg/kg)	Range of Concentrations (mg/kg)*	Maximum Detect (mg/kg)	Frequency of Detects
Aroclor-1260	6	2	0.033	[0.035] to 0.055	0.055	2/6
*Values in square brackets indicate nondetected results.						

TABLE 3.1-14

FREQUENCY OF DETECTED ORGANIC CHEMICALS IN REACH P-3

Analyte	Number of Analyses	Number of Detects	EQL (mg/kg)	Range of Concentrations (mg/kg)*	Maximum Detect (mg/kg)	Frequency of Detects
Aroclor-1260	8	1	0.033	[0.036] to [0.046]	0.041	1/8
*Values in square brackets indicate nondetected results.						

TABLE 3.1-15

FREQUENCY OF DETECTED ORGANIC CHEMICALS IN REACH P-4

Analyte	Number of Analyses	Number of Detects	EQL (mg/kg)	Range of Concentrations (mg/kg)*	Maximum Detect (mg/kg)	Frequency of Detects
Acenaphthene	9	1	0.33	0.219 to [0.344]	0.219	1/9
Anthracene	9	1	0.33	[0.329] to 0.369	0.369	1/9
Benz(a)anthracene	9	2	0.33	0.035 to 0.609	0.609	2/9
Benzo(a)pyrene	9	1	0.33	[0.329] to 0.675	0.675	1/9
Benzo(b)fluoranthene	9	2	0.33	0.05 to 0.91	0.91	2/9
Benzo(g,h,i)perylene	9	1	0.33	[0.329] to 0.473	0.473	1/9
Benzo(k)fluoranthene	9	1	0.33	0.114 to [0.344]	0.114	1/9
Chrysene	9	2	0.33	0.034 to 0.6	0.6	2/9
Di-n-octylphthalate	9	1	0.33	0.094 to [0.344]	0.094	1/9
Dibenzofuran	9	1	0.33	0.18 to [0.344]	0.18	1/9
Fluoranthene	9	3	0.33	0.056 to 1.277	1.277	3/9
Fluorene	9	1	0.33	0.294 to [0.344]	0.294	1/9
Indeno(1,2,3-cd)pyrene	9	1	0.33	[0.329] to 0.455	0.455	1/9
2-Methylnaphthalene	9	1	0.33	0.167 to [0.344]	0.167	1/9
Naphthalene	9	1	0.33	[0.329] to 0.374	0.374	1/9
Phenanthrene	9	1	0.33	[0.329] to 1.505	1.505	1/9
Pyrene	9	3	0.33	0.051 to 1.055	1.055	3/9
*Values in square brackets indicate nondetected results.						

In summary, 29 organic chemicals were retained as COPCs because they were positively detected in at least one sample, as presented in Table 3.1-16.

TABLE 3.1-16

RESULTS OF ORGANIC DATA REVIEW

Analyte	Result	Rationale
Aroclor-1254	Retained as a COPC	Detected in reach P-1 samples only.
Aroclor-1260	Retained as a COPC	Detected in reaches P-1, P-2, and P-3.
Aldrin	Retained as a COPC	Detected in reach P-1 samples only.
δ-BHC	Retained as a COPC	Detected in reach P-1 samples only.
α-Chlordane	Retained as a COPC	Detected in reach P-1 samples only.
γ-Chlordane	Retained as a COPC	Detected in reach P-1 samples only.
4,4'-DDT	Retained as a COPC	Detected in reach P-1 samples only.
Acenaphthene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Acenaphthylene	Retained as a COPC	Detected in reach P-1 but not included in the analytical suite for reaches P-2 and P-3.
Anthracene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Benz(a)anthracene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Benzo(a)pyrene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Benzo(b)fluoranthene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Benzo(g,h,i)perylene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Benzo(k)fluoranthene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Benzoic acid	Retained as a COPC	Detected in reach P-1 but not included in the analytical suite for reaches P-2 and P-3.
Bis(2-ethylhexyl)phthalate	Retained as a COPC	Detected in reach P-1 but not included in the analytical suite for reaches P-2 and P-3.
Carbazole	Retained as a COPC	Detected in reach P-1 but not included in the analytical suite for reaches P-2 P-3, and P-4.
Chrysene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Di-n-octylphthalate	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Dibenz(a,h)anthracene	Retained as a COPC	Detected in reach P-1 but not included in the analytical suite for reaches P-2 and P-3.
Dibenzofuran	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Fluoranthene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Fluorene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Indeno(1,2,3-cd)pyrene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
2-Methylnaphthalene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Naphthalene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Phenanthrene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.
Pyrene	Retained as a COPC	Detected in reaches P-1 and P-4 but not included in the analytical suite for reaches P-2 and P-3.

3.2 Nature and Sources of Contamination

Contamination in Pueblo Canyon sediments was investigated using a combination of full-suite, limited-suite, and key contaminant analyses; statistical analyses of the analytical data; and detailed geomorphic mapping and physical characterization of post-1942 sediments. In this section we discuss the nature, characteristics, and probable sources of contaminants that were identified as COPCs in Section 3.1, including evidence for the possible collocation of contaminants. These COPCs include 6 radionuclides, 8 inorganic chemicals, and 29 organic chemicals. Identifying the sources of contaminants is an important part of the conceptual model that describes their distribution, and evidence pertaining to the sources of each COPC is discussed in this section. Available data indicate that the source for most or all of the COPCs is upstream of the confluence of Acid Canyon and Pueblo Canyon, either within the Acid Canyon watershed or within the main Pueblo Canyon watershed. The relation of each COPC to plutonium-239,240 is given particular attention because of the use of plutonium-239,240 as a key contaminant in this investigation. Additional details on all the COPCs are presented in Appendix E, and a detailed discussion of plutonium-239,240 is presented in Section 3.3.

Several graphical methods are used in this section to visually present variations in the COPCs within reaches and between reaches. For all COPCs, summary figures are presented that show the normalized maximum value of COPCs relative to background values (or, in the case of organic chemicals, the EQL); values below 1.0 on these figures indicate results below the background values. To highlight the pattern of COPCs between reaches, the chemicals are ordered within each group (organic chemicals, inorganic chemicals, and radionuclides) from highest to lowest for reach P-1. Thus, the normalized values for P-1 follow a decreasing trend by chemical. Where values for other reaches also follow a decreasing trend, a positive correlation in maximum values between reaches is suggested. Note that the “maximum” results for some COPCs are actually for samples with concentrations reported as below detection limits, but they are considered here to possibly represent detects to provide conservative estimates of potential levels of contamination. Other summary figures show only values reported as above detection limits because these results may more accurately portray the true levels of contamination.

Other graphical methods used to present data on COPCs in the Pueblo Canyon sediment samples include plots of analyte concentration versus distance downstream from Acid Canyon for representative COPCs. For some inorganic and organic COPCs, these plots distinguish results reported as above and below detection limits to allow better interpretation of the data and uncertainties associated with high detection limits for some analytes. Finally, a scatter plot matrix is shown for the radionuclide COPCs, which indicates strong correlations between concentrations of some radionuclides, in turn indicating collocation of these COPCs within the sediments.

3.2.1 Inorganic COPCs

Eight inorganic chemicals were identified as COPCs in Section 3.1: antimony, cadmium, copper, lead, mercury, selenium, silver, and zinc. The nature, distribution, and possible sources for each inorganic COPC were evaluated using statistical analyses, which are presented in more detail in Appendix E, in combination with examination of the specific geographic and geomorphic setting of the samples in which these analytes were detected above background values.

Figure 3.2-1 shows maximum results for the inorganic COPCs normalized by background values. The upper plot is based on either the maximum value for an analyte, where it is a detected sample result, or the detection limit for other analytes. The lower plot uses only detected sample results. As discussed in Section 3.1, the black sand sample from P-4 East (04PU-96-0026) was excluded from this data set because this sample has a high but naturally-occurring concentration of zinc (and of other inorganic chemicals not identified as COPCs). The maximum normalized value is less than seven (for mercury in reach P-1), indicating the relatively low concentrations of these chemicals. Five inorganic COPCs (mercury, lead, cadmium, zinc, and silver) show a similar trend in maximum concentrations, with the highest concentrations occurring in reach P-1 samples and smaller differences from background values existing in the other reaches (Figure 3.2-1). Plots of all results for mercury and lead versus distance from Acid Canyon, presented in Figure 3.2-2, also show that the highest concentrations and the highest percentage of sample results above the background values occur in P-1. These results suggest that the primary source for these contaminants in the Pueblo Canyon watershed is upstream of the confluence with Acid Canyon, either within the Acid Canyon basin of the upper Pueblo Canyon basin.

Three of the inorganic COPCs (antimony, copper, and selenium) display patterns of maximum values in Figure 3.2-1 that are less regular than for the other inorganic COPCs. Antimony was not detected in any sample and is included as a COPC solely because of detection limits above the background value in the full-suite sampling events in reaches P-1 and P-4. In contrast, analyses from limited-suite sampling events in all reaches had detection limits below the background value and provide evidence that antimony is not present above the background value in Pueblo Canyon sediments. The highest detected sample results for the other two inorganic COPCs, copper and selenium, were obtained in P-2 West, which indicates the possibility of additional sources of contaminants downstream from Acid Canyon. However, interpretation of the selenium results are confounded by elevated detection limits and an overall low detection frequency, as discussed later in this section.

Most of the inorganic COPCs (cadmium, copper, lead, mercury, silver, and zinc) were detected at levels above background values in sediment samples from reach P-1 West, upstream from Acid Canyon, and thus indicate releases from sites other than Technical Area (TA) -45. These include a sample (04PU-97-0082, with results supported by quality assurance [QA] duplicate 04PU-97-0083) that has the highest result for silver (1.7 mg/kg), the second highest result for mercury (0.49 mg/kg), and the third highest result for zinc (95.8 mg/kg). Most of these analytes, with the exception of cadmium, were also detected at levels above background values in sludge at the Pueblo Canyon Wastewater Treatment Plant (WWTP) (PRS 0-018[a]) (LANL 1997, 56614), suggesting that this may be a source for some of the inorganic contaminants in Pueblo Canyon sediments. However, P-1 West is also downstream from developed areas in the Los Alamos townsite, and some of these inorganic COPCs may also be derived from other sources.

Three of the inorganic COPCs (lead, selenium, and zinc) were detected at levels above background values in sediment samples from Acid Canyon during this investigation, and two others (mercury and silver, along with lead) were detected at levels above background values during previous investigations in Acid Canyon (LANL 1995, 48856). Thus, some of the inorganic COPCs in Pueblo Canyon sediments were probably derived from TA-45 and/or other sources in the Acid Canyon drainage basin, and COPCs in sediments downstream from Acid Canyon probably have multiple sources.

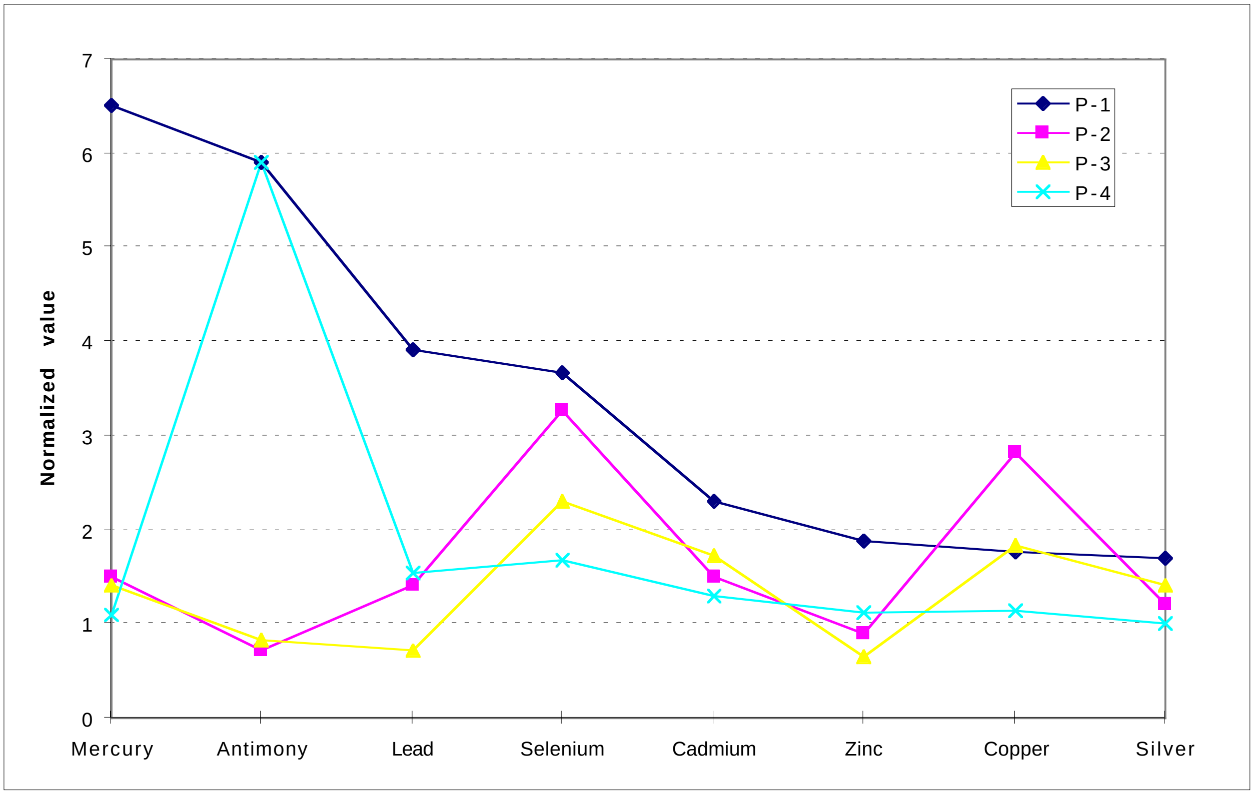


Figure 3.2-1a. Maximum inorganic chemical results (of either detected or nondetected values) normalized by background values.

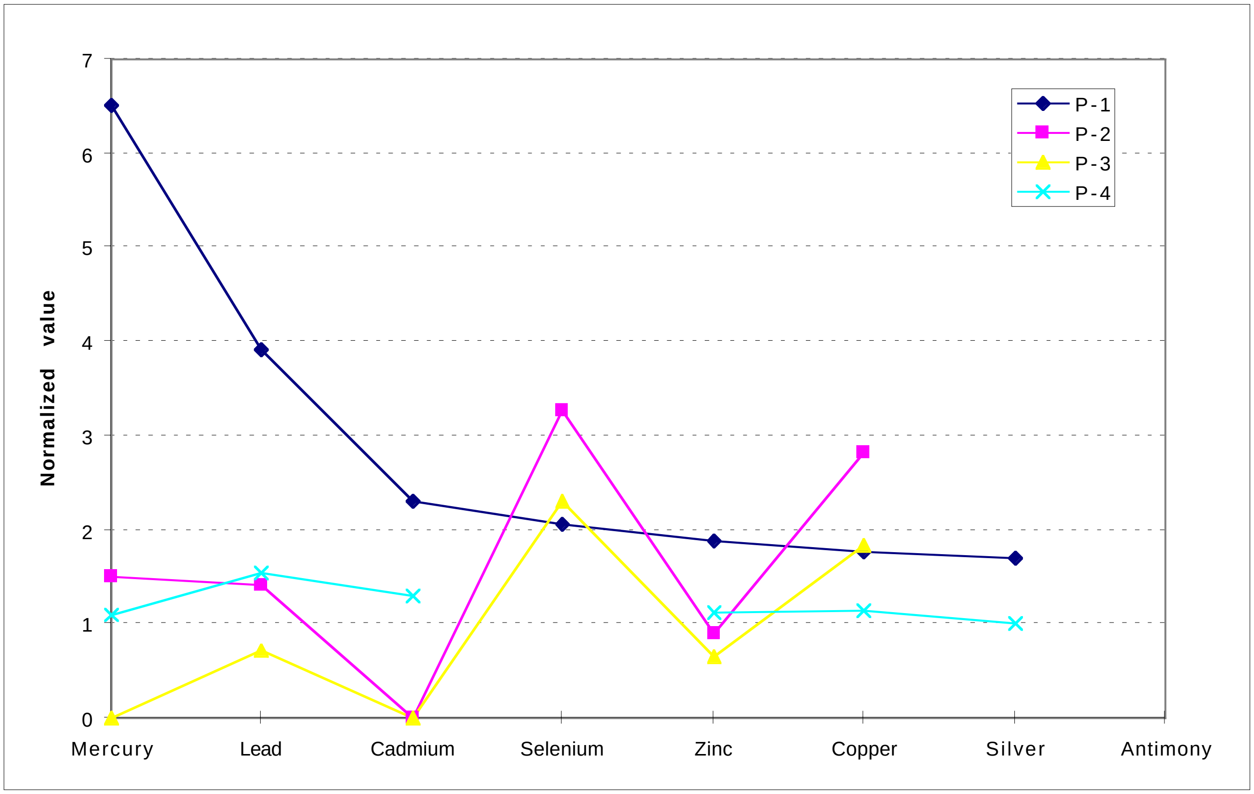


Figure 3.2-1b. Maximum detected inorganic chemical results normalized by background values.

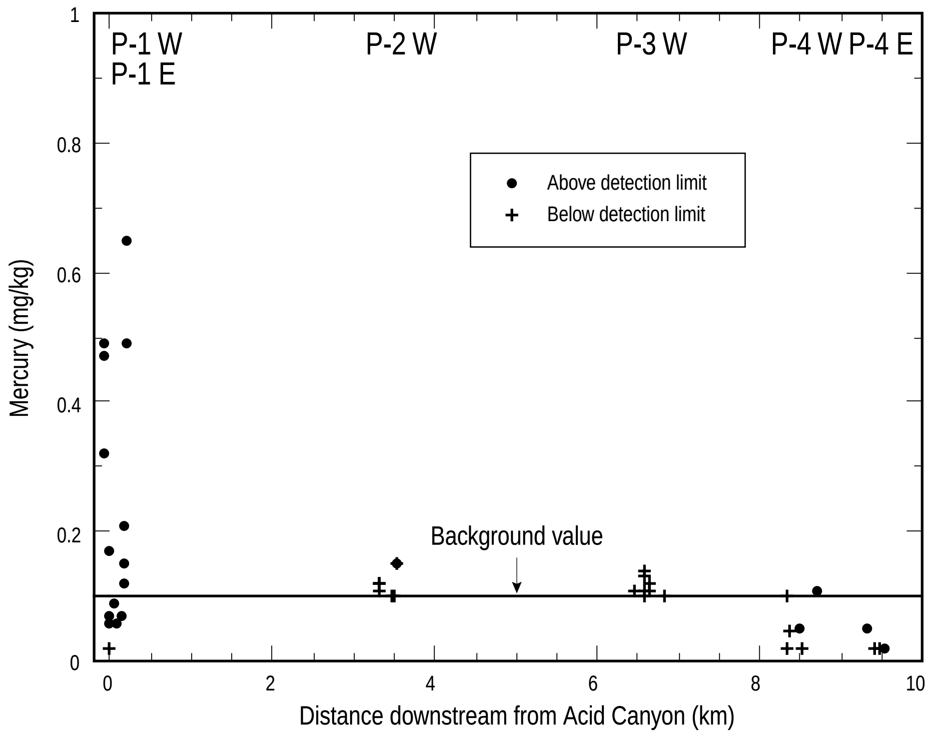
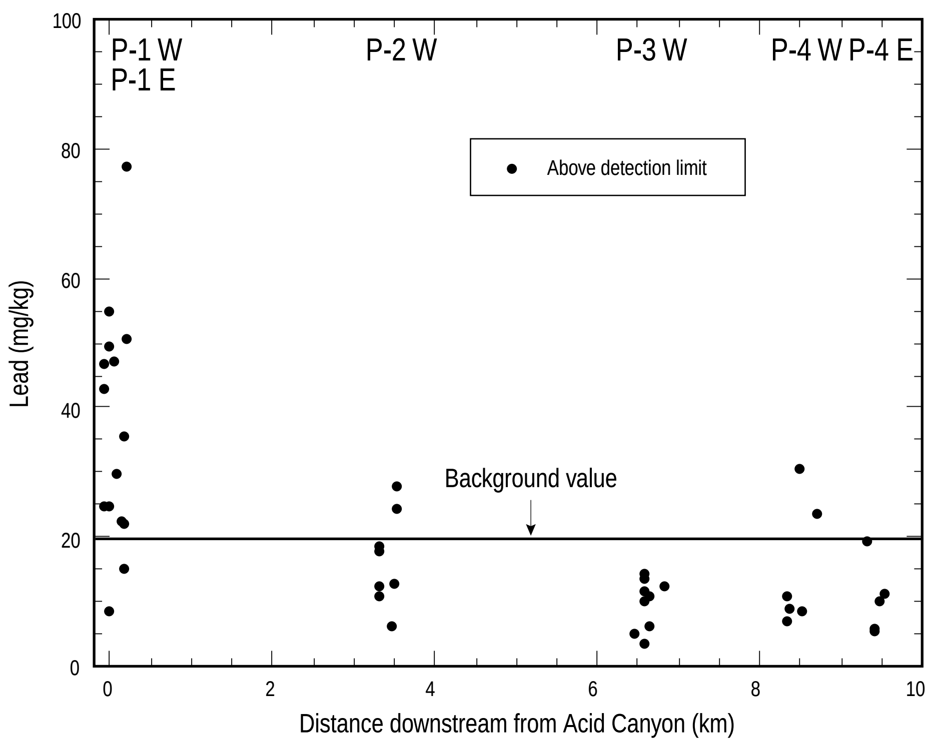


Figure 3.2-2a. Plot of the concentration of mercury versus distance downstream from Acid Canyon.



F3.2-2ab / PUEBLO CANYON REACH RPT / 102398

Figure 3.2-2b. Plot of the concentration of lead versus distance downstream from Acid Canyon.

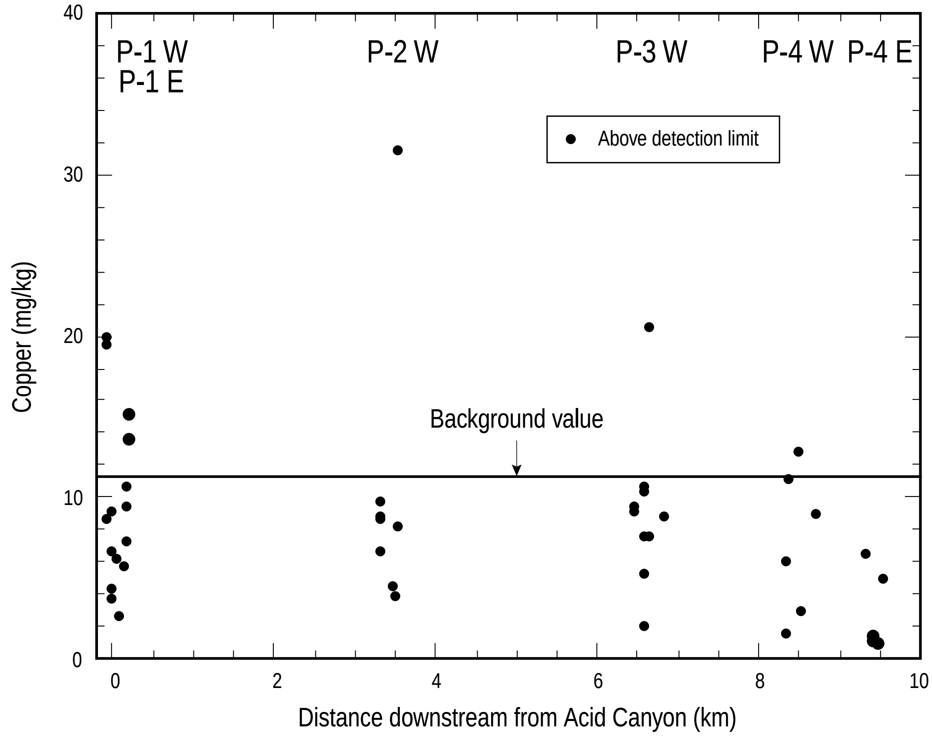


Figure 3.2-2c. Plot of the concentration of copper versus distance downstream from Acid Canyon.

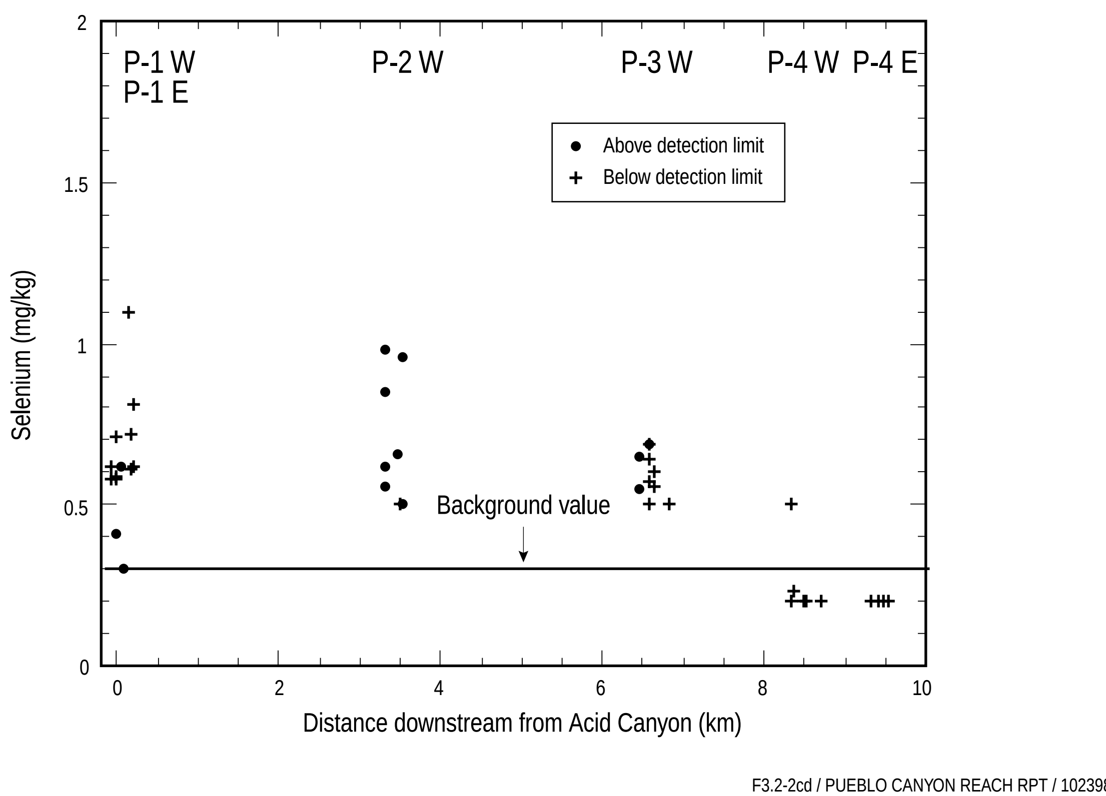


Figure 3.2-2d. Plot of the concentration of selenium versus distance downstream from Acid Canyon.

Statistical analyses presented in Appendix E do not show clear correlations of any of the inorganic COPCs with plutonium-239,240; thus, the extensive data set on plutonium-239,240 in Pueblo Canyon sediments cannot be used to reliably estimate concentrations of the inorganic COPCs. This lack of consistent collocation may be the result of variable mixing of contaminants that have different sources and different release histories, including the effects of treatment processes that varied through time, combined with analytical uncertainties associated with the low concentrations of the inorganic COPCs. However, close examination of the analytical results indicates that there may be partial collocation of the inorganic COPCs with plutonium-239,240 downstream of Acid Canyon. For example, all the detected inorganic COPCs except selenium are present at above background values in the sample with the highest plutonium-239,240 value (sample 04PU-96-0128, c2b unit of reach P-1 East), including the highest cadmium value (0.92 mg/kg), suggesting that all of these chemicals were being released from TA-45 or other sources contemporaneously with the peak releases of plutonium.

The two inorganic COPCs that have their highest results in reach P-2 West, copper and selenium, may indicate additional contaminant sources downstream from Acid Canyon. Potential sources east of Acid Canyon include TA-31, TA-73, and the Central WWTP, as discussed in Section 1.3.2, as well as sources in the Los Alamos townsite not related to Laboratory operations. However, results for both of these COPCs are problematic. The maximum result for copper (31.5 mg/kg, sample 04PU-97-0212) is the only copper result in P-2 West above the background value of 11.2 mg/kg (Figure 3.2-2), which limits the practical significance of this result. Also, as discussed earlier, copper apparently has additional sources upstream from reach P-1 West.

Selenium was detected at levels above the background value of 0.3 mg/kg in seven of the eight results from P-2 West, including the three highest results in the reach samples (0.85 to 0.98 mg/kg in samples 04PU-97-0209, 04PU-97-0210, and 04PU-97-0211), which could suggest widespread distribution of low levels of selenium. However, as noted in Section 3.1.1, it is important to recognize that all of the apparently elevated selenium results are derived from two of the five analytical laboratories used for inorganic analyses, and potential problems are recognized with selenium analyses from these laboratories. Therefore, the selenium sample results should be interpreted carefully in terms of both variation in detection limits and potential interlaboratory differences in specific sample preparation or analytical methods. The results are not conclusive that there were selenium releases downstream of reach P-1 and upstream of reach P-2 in the Pueblo Canyon watershed.

3.2.2 Radionuclide COPCs

Six radionuclides were identified as COPCs in Section 3.1: americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90; and tritium. All these radionuclides have been reported above background values by some prior investigations at TA-45 and downstream from TA-45 (LANL 1981, 6059; LANL 1996, 54468), although reported tritium levels are not greatly different from background values. Therefore, the characteristics of the radionuclide COPCs within Pueblo Canyon sediments are largely consistent with discharges from TA-45 into Acid Canyon, as discussed below. However, plutonium-239,240 has also been reported below a septic tank outfall farther west in Acid Canyon (PRS 0-030[g]) (LANL 1995, 51983), and it is possible that some of the plutonium in Pueblo Canyon was derived from this source.

The normalized plot for the radionuclides, Figure 3.2-3, is based on the reported values for each radionuclide (results were not censored by the minimum detectable activity value where both a sample result and the minimum detectable activity were reported). The gamma-spectroscopy results were used for americium-241 to obtain a larger and more representative sample set and thus the alpha-spectroscopy results were not used for this radionuclide. The normalized plot shows that plutonium-239,240 exceeds the background value by nearly four orders of magnitude in reach P-1. This observation supports the selection of plutonium-239,240 as the key contaminant for the Pueblo Canyon reaches. The normalized plot shows a striking common trend in maximum values reported for three radionuclides with large exceedances of background (plutonium-239,240; plutonium-238; and americium-241). Tritium also exhibits a similar pattern, but interpretation of the tritium data is limited by the lack of tritium data for reaches P-2 and P-3. Cesium-137 and strontium-90 were detected at values slightly above background in reach P-1 but were less than the background values in the other reaches (although no strontium-90 analyses were obtained from P-2 or P-3). All radionuclide COPCs appear to be derived from the Acid Canyon basin, which is expected based on knowledge of contaminant releases from TA-45 into Acid Canyon during early Laboratory operations.

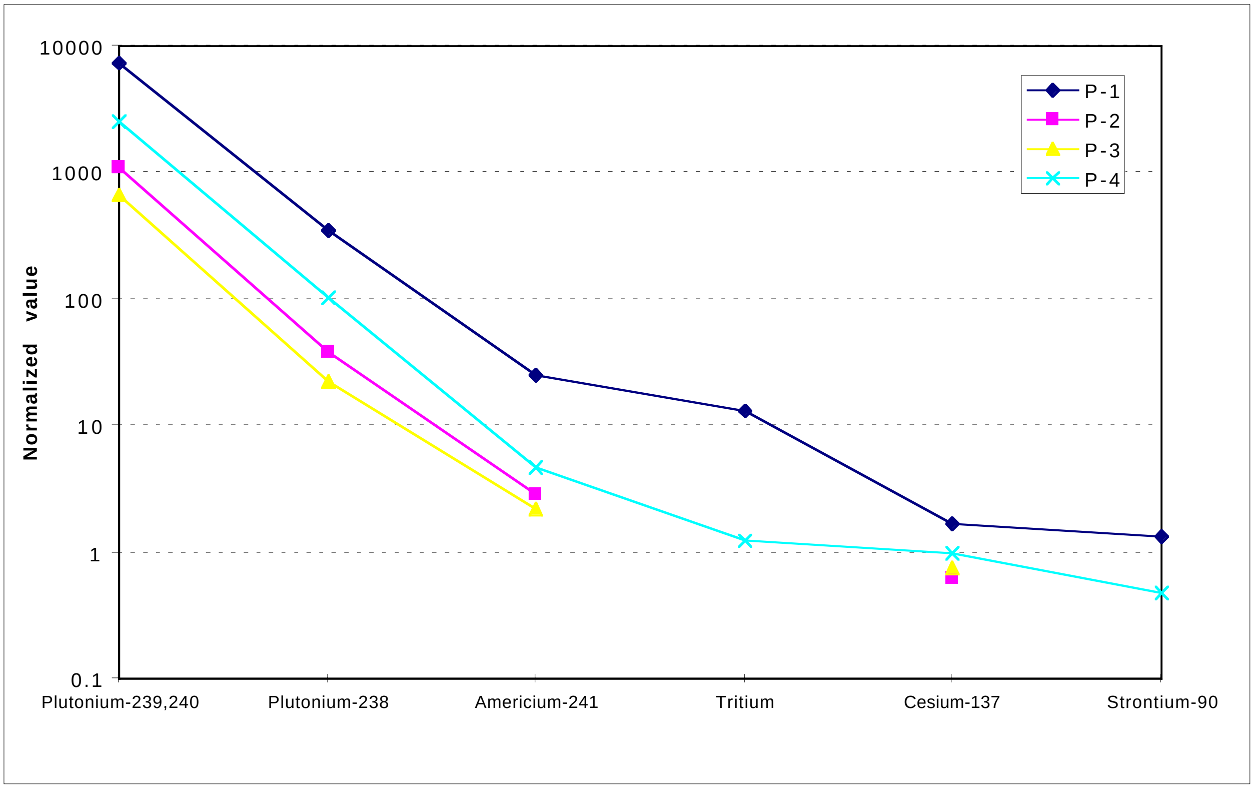


Figure 3.2-3. Maximum radionuclide results normalized by background values

The possible collocation of radionuclide COPCs was evaluated in part using the scatter plot matrix of Figure 3.2-4. To facilitate interpretation of the correlation between radionuclides, the scatter plot matrix shows the paired sample results, and the ellipse shown on each scatter plot encloses 95% of the data. Cases where the ellipse approaches a line suggests a highly significant statistical correlation. Appendix E provides additional information on the statistical correlation of radionuclide COPCs. Most of the radionuclide COPCs display good positive correlations with each other, which is consistent with these radionuclides sharing similar histories of release and subsequent transport and which allows concentrations of these COPCs to be estimated in sediments where only the concentration of plutonium-239,240 has been evaluated. Ratios of collocated radionuclides are estimated by calculating averages from specific samples that agreed with linear regressions through all the data. On average in Pueblo

Canyon, americium-241 is present at concentrations approximately 2.6% of the plutonium-239,240 concentration, and plutonium-238 is present at approximately 0.5%. Tritium is present at 0.2% of the plutonium-239,240 concentration in the sample with the highest levels of both radionuclides, although there are too few tritium analyses to evaluate the reliability of this ratio. In addition, the apparent correlation of tritium to americium-241; plutonium-238; and plutonium-239,240 is controlled by a single tritium result above the background value from the same sample that yielded the highest concentrations of these other radionuclides (1.208 pCi/g in sample 04PU-96-0128, c2b unit of reach P-1 East). Therefore, identification of tritium as a COPC and its possible collocation with other radionuclides may not be reliable.

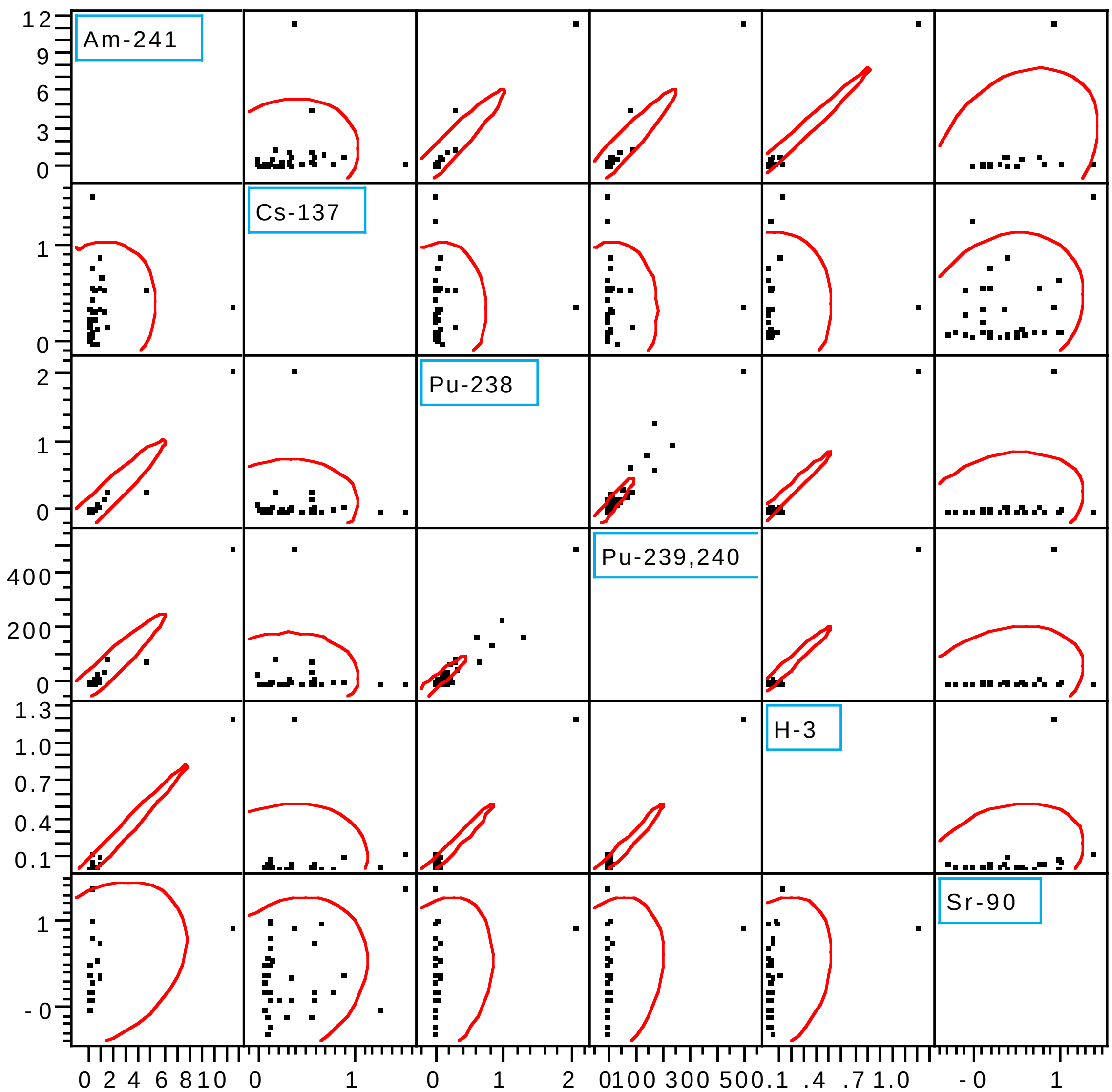


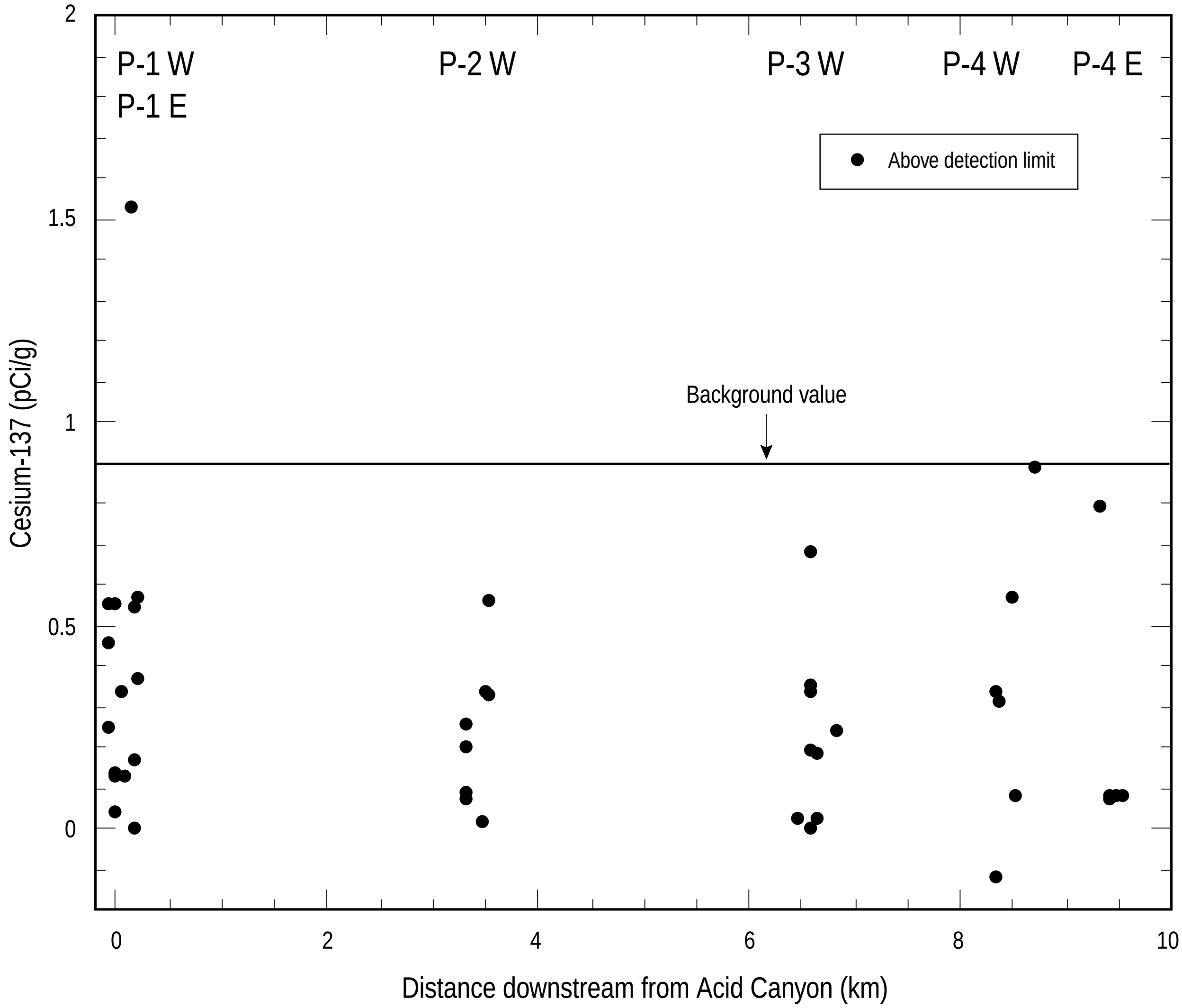
Figure 3.2-4. Scatter plot matrix of radionuclide COPCs.

Two radionuclides that were identified as COPCs in Section 3-1, cesium-137 and strontium-90, do not display good correlation with the other radionuclide COPCs (Figure 3.2-4). The inclusion of cesium-137 as a COPC was primarily based on a single result above the background value (1.53 pCi/g in sample 04PU-96-0129, f1 unit of reach P-1 East). All other cesium-137 results are below the background value (Figure 3.2-5). Because of the lack of correlation with the other radionuclides known to be derived from TA-45 and because of the low cesium-137 concentrations in the other samples, the identification of cesium-137 as a COPC may not be reliable. Strontium-90 has a single result above the background value, which is also in the same sample as the elevated cesium-137 result (1.4 pCi/g in sample 04PU-96-0129). In contrast to cesium-137, the strontium-90 analyses apparently display a statistical distribution shift relative to background data (Figure E2-5) that indicate releases from TA-45. The lack of correlation between strontium-90 and plutonium-239,240 may be due to either differential transport of these two radionuclides (with strontium-90 being more soluble) or different release histories such that the peak strontium-90 releases may not have been contemporaneous with the peak plutonium-239,240 releases.

3.2.3 Organic COPCs

Twenty-nine organic chemicals were detected at low levels in the Pueblo Canyon sediment samples and therefore identified as COPCs, as discussed in Section 3.1. Analyses for seven of these organic COPCs, including PCBs and pesticides, were obtained in all four reaches, and analyses for the remaining 22 semivolatile organic COPCs were obtained only in the full-suite analyses in reaches P-1 and P-4. The SVOCs are mostly within two chemical groups, either polycyclic aromatic hydrocarbons (PAHs) or plasticizers. Low levels of all these specific chemical groups (PCBs, pesticides, PAHs, and plasticizers) are commonly found to be associated with areas receiving runoff from light industrial settings at the Laboratory and urban settings in the Los Alamos townsite, whereas significant releases of such chemicals from the Laboratory should be recognizable by large exceedances of the detection limit in sample results. Therefore, the relatively low levels found in the Pueblo Canyon sediment samples may represent only small releases and/or dispersed sources.

In the normalized plots for organic chemicals in Figure 3.2-6, the maximum result is used whether it is a detect or nondetect result, and most of the maximum values for reach P-1 are detects. Figure 3.2-6a presents the normalized plot for PCBs and pesticides, and Figure 3.2-6b presents the normalized plot for SVOCs. The highest ratio of an organic chemical concentration to its detection limit is less than 10 (for bis[2-ethylhexyl]phthalate in reach P-1), and none of the organic COPCs measured much above the detection limit in reach P-4. Phenanthrene is the only organic chemical that has a Pueblo Canyon maximum sample result in reach P-4, although the highest detected results for other analytes were reported in P-4 samples associated with unusually low detection limits. All other organic chemicals have the highest Pueblo Canyon sample result from reach P-1, although interpretation of the organic data is somewhat limited by the lack of SVOC data from reaches P-2 and P-3. However, because the concentrations of SVOCs are similar between reaches P-1 and P-4, the lack of SVOC data from P-2 and P-3 should not lead to greatly underestimating maximum SVOC concentrations. This potential bias in the maximum SVOC concentrations will be evaluated in context of the screening-level human health and ecological risk calculations presented in Section 5.



F3.2-5 / PUEBLO CANYON REACH RPT / 102398

Figure 3.2-5. Plot of cesium-137 concentration versus distance downstream from Acid Canyon.

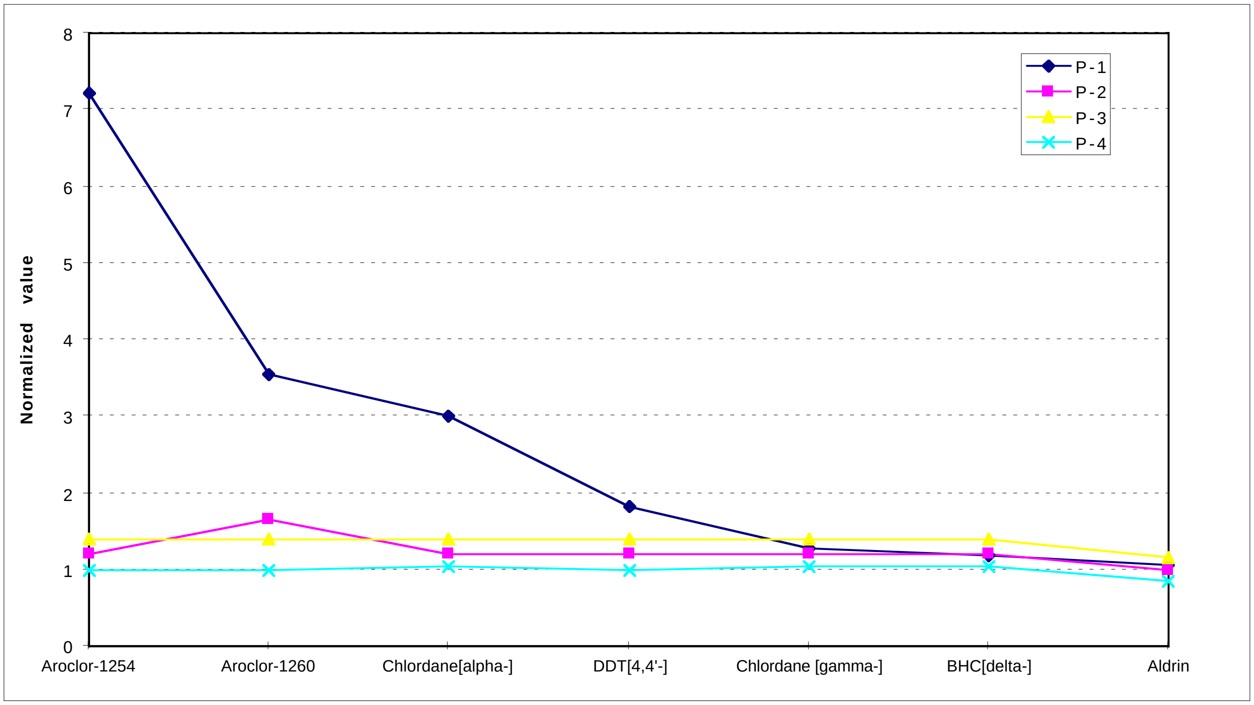


Figure 3.2-6a. Maximum PCB and pesticide chemical results normalized by EQLs.

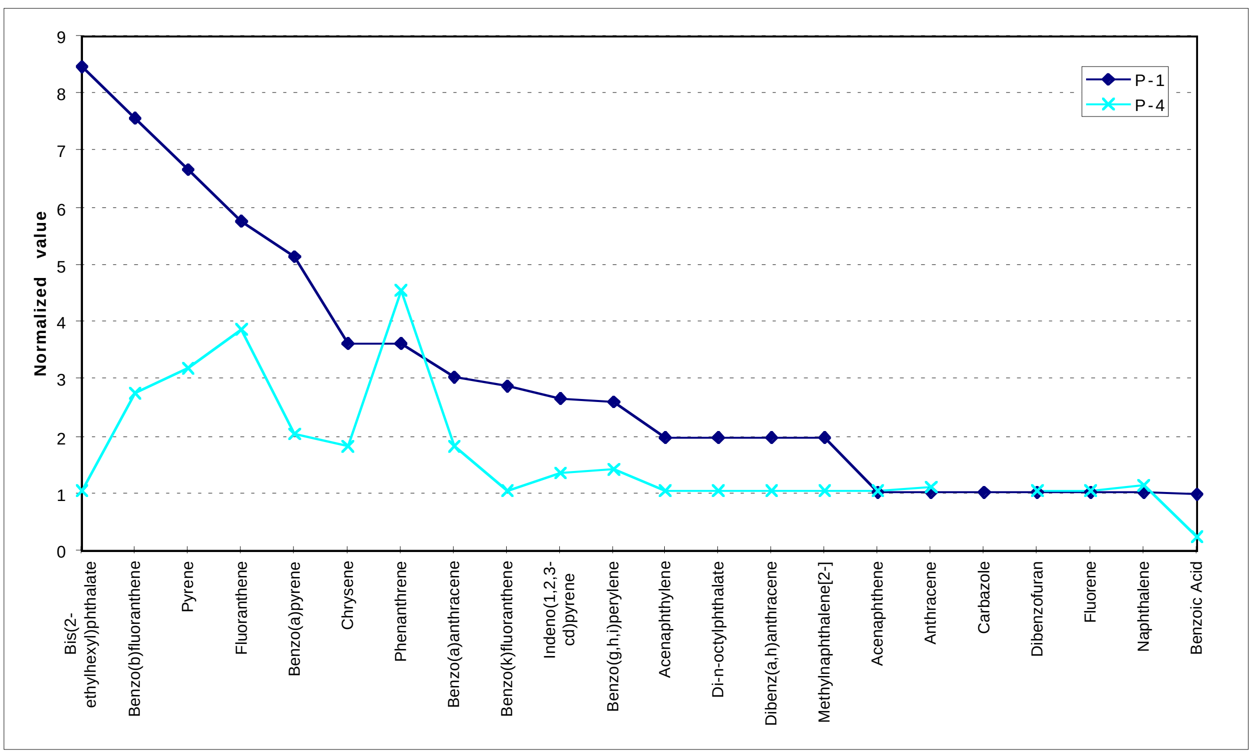


Figure 3.2-6b. Maximum SVOC chemical results normalized by EQLs.

Of the seven organic COPCs in the PCB-pesticide suite, all except one, the PCB Aroclor-1260, were detected only in reach P-1, indicating that there are no major sources of PCBs or pesticides in the lower portions of the Pueblo Canyon watershed (including PRSs at TA-31 and TA-73). Plots of sample results versus distance from Acid Canyon are shown in Figure 3.2-7 for representative analytes in this suite. Aroclor-1260 was detected in reaches P-1 West, P-1 East, P-2 West, and P-3 West, and the highest value was obtained from the sample with the highest plutonium-239,240 in Pueblo Canyon (0.117 mg/kg in sample 04PU-96-0128 in the c2b unit of P-1 East). This same sample also had the only detected value for the PCB Aroclor-1254 (0.238 mg/kg), although no other analytes in this suite were detected in this sample. Both the frequency of detected PCBs and the reported concentrations are higher in P-1 than in either P-2 or P-3, suggesting that the primary source for these contaminants in the Pueblo Canyon sediments is either within Acid Canyon or within the Pueblo Canyon basin upstream from Acid Canyon. Five of these seven organic COPCs were also detected in sludge at the Pueblo Canyon WWTP (PRS 0-018[a]) (LANL 1997, 56614), suggesting that this PRS may constitute one source for these organic COPCs. PCBs have also been reported at the outfall of a septic tank in the Acid Canyon basin (PRS 0-030[g]) (LANL 1995, 51983), suggesting that there may be multiple sources for these contaminants. Because these areas drain parts of the Los Alamos townsite, it is possible that some of these organic contaminants had other sources unrelated to Laboratory operations.

For the 22 organic COPCs that were analyzed only in samples from reaches P-1 and P-4 (all PAHs or plasticizers in the SVOC category), the frequency of detects was higher in P-1 for all analytes except one, di-n-octylphthalate, which was detected only in one sample in P-4 (note that for one of these analytes, carbazole, no analyses are available from P-4). The higher frequency of detects in P-1 than in P-4 may suggest a primary source for this suite of organic COPCs in the upper Pueblo Canyon watershed, as is also inferred for the PCB-pesticide suite. However, other characteristics of the data set suggest that there are multiple sources for the SVOCs in the watershed. Specifically, maximum detected values were obtained in P-1 for 14 of the SVOCs and in P-4 for 8 of the SVOCs, an observation that is consistent with the existence of multiple sources. Also, concentrations are similar between the two reaches, which suggests that similar concentrations may exist in P-2 and P-3. These observations suggest that the PAHs and plasticizers may have been derived from nonpoint sources in the Pueblo Canyon watershed, such as the numerous roadways and parking areas in commercial and residential areas in the Los Alamos townsite. Various materials such as charcoal and coal that have been observed within Pueblo Canyon sediments might also contribute to some of the low-level SVOC detects.

Notably, all but three of the maximum detected values for these semivolatile organic COPCs occur in two samples, one in P-1 East and the other in P-4 West. The P-1 East sample (04PU-96-0127) is a surface sample from relatively fine-grained overbank facies sediments in the c2b unit and has the maximum detected value for 12 of these organic COPCs. The fact that 04PU-96-0127 is a surface sample suggests a relatively young age for these sediments, and the fact that the sample site is close to the Los Alamos County sewer line and the associated dirt road suggests that the contaminants could be related to these potential source areas. The P-4 West sample (04PU-96-0032) is a surface sample from channel facies sediments in the c5 unit and has the maximum detected value for seven of the organic COPCs, although the reported value for four of these COPCs is less than the detection limit for other samples in the same batch, and two others are close to the detection limit. Characteristics of this sample site are very dissimilar to the P-1 East sample site in that it is coarse-grained and relatively old (believed to date to the early 1950s). Also, the sample site is not close to any road and it is unlikely to have been affected by recent surface activities.

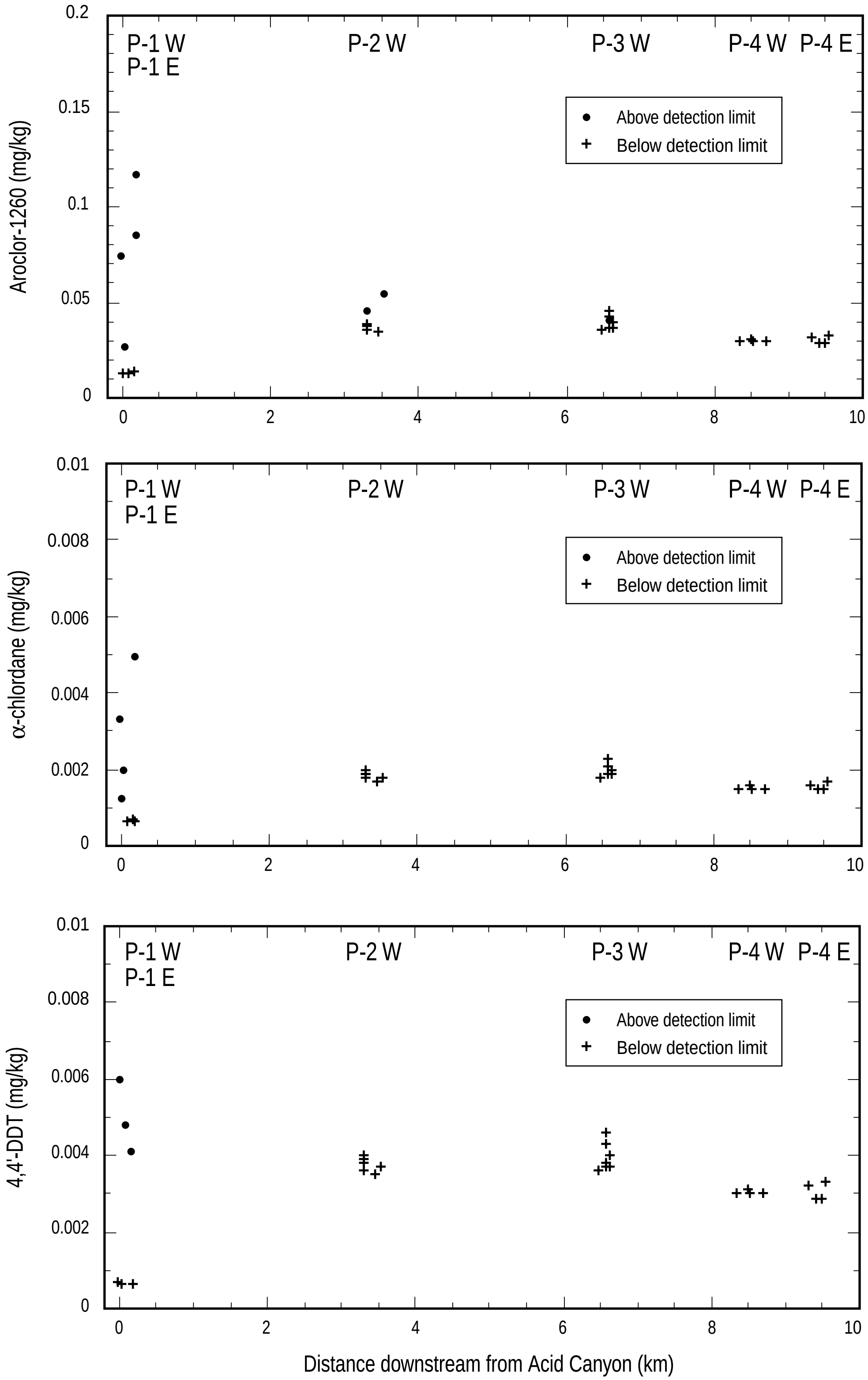


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Figure 3.2-7. Plots of the concentration of Aroclor-1260; α-chlordane; and 4,4'-DDT versus distance downstream from Acid Canyon.

In summary, a series of organic COPCs have been detected at relatively low levels in the sediments of Pueblo Canyon, but their sources and distributions are only partially understood. The geomorphic and geographic context of these samples suggests that there may be multiple sources, primarily upstream of reach P-1 East but also possibly including sites east of P-1 East. Available data also suggest that the times of contaminant release may vary among analytes from early in the post-1942 period until fairly recently. Concentrations of these organic COPCs do not correlate with concentrations of plutonium-239,240, as discussed in Appendix E; thus, the extensive data set on plutonium-239,240 in Pueblo Canyon sediments cannot be used to reliably estimate concentrations of the inorganic COPCs. It is also important to note that many of the detects are very close to detection limits, which limits the interpretation of these data. However, the preponderance of nondetect values at the typical detection limits seems consistent with small quantities of organic chemicals being transported into sediments from point and nonpoint contaminant sources.

3.3 Key Contaminant Analyses

Plutonium-239,240 (often referred to simply as “plutonium” in this section) was selected as a key contaminant for all Pueblo Canyon reaches because sediment sampling and analysis by other programs before this investigation (LANL 1981, 6059; Ferenbaugh et al. 1994, 58672), supported by the full-suite analyses of this investigation, indicate that plutonium-239,240 constitutes the most significant COPC in Pueblo Canyon. In addition, the full-suite analyses indicate that plutonium-239,240 is generally collocated with other radionuclide COPCs, which allows concentrations and inventories of such analytes to be estimated based on plutonium concentrations. Thus, most samples were analyzed only for isotopic plutonium (plutonium-238 and plutonium-239,240 [unresolved isotopes]) to allow cost-effective evaluation of the distribution of contaminants and testing components of the conceptual model.

In this section the plutonium data for each reach are presented, and the discussion is focused on examining the variations in plutonium-239,240 concentration among geomorphic units and sedimentary facies in each reach and the effects of particle size variations and sediment age on levels of plutonium. In addition, these data are combined with data on the areas, thicknesses, and density of post-1942 sediments in the geomorphic units to calculate approximate plutonium inventories by unit and by reach. In Section 4 these data are used to refine the conceptual model for plutonium transport and distribution in Pueblo Canyon, and in Section 5 the plutonium data and data on the other COPCs are used to prepare preliminary assessments of human and ecological risk.

3.3.1 Geomorphic and Statistical Evaluation of Plutonium Data

Plutonium concentrations within the sediments of Pueblo Canyon vary by several orders of magnitude, and this variability is affected by the age of the sediment relative to the time of contaminant releases, the physical processes of sediment transport, the mixing of sediment from a variety of sources, and other factors. The geomorphic and statistical evaluation of this complex data set is a critical part of this investigation that is essential for evaluating variations in risk within a reach and between reaches, understanding the effects of future transport, and developing remediation strategies, if required. Aspects of the geomorphic and statistical evaluation of the plutonium data that pertain to subsequent discussions of each reach are presented below.

3.3.1.1 Binning of Plutonium Data

The plutonium-239,240 data collected in this investigation were examined to determine what grouping of samples in each reach was optimal for the combined purposes of defining geomorphic variations in plutonium concentration and statistically describing the variability in plutonium concentration. These grouped or “binned” data are used in the geomorphic assessments and human health risk assessments in this report and therefore the specific binning process is an important part of the data evaluation. The variability in contaminant concentrations within these bins were also used in the sample allocation process discussed in Section 2.2.4, and can be used in future uncertainty analyses as proposed in the core document (LANL 1997, 55622; LANL 1998, 57666). The binning process is discussed here to document the specific rationale used in this investigation.

The plutonium data in each subreach were first examined after being grouped or “binned” by individual geomorphic units and sediment facies, and where appropriate these subsets of data were combined into larger bins to increase sample size and allow better statistical evaluation. In some cases additional subdivisions within a geomorphic unit were defined, particularly where plutonium concentrations were highest (e.g., subdividing a buried stratigraphic interval with higher plutonium from near surface sediments with lower plutonium). Channel facies and overbank facies samples were kept in separate bins in all reaches because maximum and average plutonium concentrations were always higher in the finer-grained overbank sediments than in related coarser-grained channel sediments. Samples within the same sediment facies in different units were kept in separate bins if the variations in plutonium concentration provided information on time-dependent trends in a reach (e.g., where c1 sediment in active channels has less plutonium than texturally similar c2 sediment in older, abandoned channel units), but these subsets were combined where no such trends were apparent in the data.

3.3.1.2 Evaluation of Effects of Sediment Age and Particle Size

Possible temporal trends in plutonium concentration in a reach were evaluated by examining the plutonium data in terms of different ages of associated geomorphic units. Constraints on absolute or relative sediment age were provided by examination of historical aerial photographs, isotopic ratios in sediments, spatial relations between geomorphic units, and/or vertical stratigraphic relations (deeper sediments being older). Because plutonium tends to occur in higher concentrations in finer-grained sediments of a given age, it is necessary to compare samples with similar particle size characteristics to determine if differences or similarities in plutonium concentration between samples allow insight into time-dependent trends. For each reach, all samples were compared on scatter plots showing the relation of plutonium-239,240 concentration to various particle size parameters (e.g., percent silt and clay, median particle size), helping to identify sediment packages that share similar relations between plutonium concentration and particle size. Scatter plots comparing plutonium data and organic matter content were also examined because plutonium has a geochemical affinity for organic matter (e.g., Langmuir 1997, 56037), and it was expected that plutonium concentration might be correlated with organic matter content. However, these plots are not presented in this report because they were not useful in understanding plutonium variability. The poor correlation between plutonium and organic matter in this data set is inferred to be caused by much of the organic matter originating from post-depositional soil development, obscuring any possible correlations that might have existed in the original flood deposits, although the plutonium might also be largely associated with mineral surfaces.

3.3.1.3 Plutonium Inventory

The approximate plutonium-239,240 inventory within each geomorphic unit and each stratigraphic subdivision of geomorphic units was calculated using the data on average plutonium concentrations (pCi/g), the estimated area (m^2) and average thickness (m) of each sediment package, sediment density (g/cm^3), and average gravel content (weight %). Area and thickness data are summarized in Section 2, sediment density measurements are discussed in Appendix B-4.0, and gravel data are presented in Appendix B-3.0. In these calculations it is assumed that the volume of each unit occupied by gravel contains no radionuclide COPCs because of the relations seen between particle size and radionuclide concentration in Pueblo Canyon sediment samples (Sections 3.3.2.2, 3.3.3.2, 3.3.4.2, and 3.3.5.2). The total plutonium inventory in each reach is normalized by reach length, as measured along the stream channel on FIMAD topographic maps, to facilitate comparison of the amount of plutonium in reaches of varying lengths and extrapolation between reaches (units of mCi/km). It should be stressed that there are uncertainties associated with each variable used in these inventory calculations, and the results of all such calculations are inherently approximate. However, a primary purpose of these calculations is to show the relative distribution of plutonium between different geomorphic units and different parts of Pueblo Canyon, to be used for the possible design of remedial actions, and assumptions made in these calculations were applied consistently between reaches. Therefore, the general pattern of variations in plutonium inventory within Pueblo Canyon is considered to be reliable although the precision of these estimates has not been estimated.

3.3.1.4 Potential Remobilization

Estimates of the percentage of the total plutonium inventory most susceptible to remobilization in each reach are made based on proximity to the active channel and the geomorphic history of channel changes as discussed in Section 2. These estimates assume a time scale of about 50 years and geomorphic processes similar to those documented to have occurred during the last 55 years (post-1942) and involve judgments as to the average residence time of sediment in the different units. Where the average sediment residence time in a particular geomorphic setting is judged to be greater than 50 years, most of the sediment is assumed to be not susceptible to remobilization, and additional sediment deposition may instead be the most important geomorphic process (e.g., most of the f1 units). All active channel sediment is assumed to be susceptible to remobilization during the next 50 years. Abandoned channel units that occur adjacent to the active channel and that record gradual channel migration, such as the c2 unit in P-1 East, are also assumed to be susceptible to remobilization. However, some areas of abandoned post-1942 channels that have been isolated from the active channel by major lateral migration, such as most of the c5 unit in P-4 West, or by abrupt changes in channel location, such as much of the c2 unit in P-2 East, are not considered to be as susceptible to remobilization during the next 50 years. Most areas of floodplain are assumed to be stable for the next 50 years, based partly on the common presence of trees greater than 100 years old, although channel migration may result in relatively small amounts of remobilization of sediment on the floodplains.

3.3.1.5 Plutonium 239/238 Ratios

Ratios of plutonium-239,240 to plutonium-238 (plutonium 239/238 ratios) were calculated from the average values in each bin in each reach and are presented in tables in this section. These ratios are typically 100 to 300 downstream from Acid Canyon and indicate the dominance of plutonium-239,240 in Pueblo Canyon. These ratios are also important in evaluating the plutonium data in reaches LA-4 and LA-5 downstream from the confluence of Pueblo and Los Alamos Canyons to distinguish the relative contribution of these two canyons, and they will be discussed further in a separate report on those reaches. Note that all of these ratios are approximate, in part because of the relatively poor precision of the plutonium-238 analyses associated with its being reported at quantities less than the detection limit in many samples. However, the calculation of plutonium 239/238 ratios using the average plutonium concentration within many samples should be more reliable than ratios calculated from individual samples because measurement uncertainties will be averaged out. In addition, sediment with the highest plutonium concentrations probably provide the most accurate estimate of plutonium 239/238 ratios in the initial releases because sediment with low concentrations may include relatively high percentages of fallout-derived plutonium.

3.3.1.6 Evaluation of Plutonium Variability in Collocated Samples

Another important consideration in the assessment of these data is the comparability of collocated sample results. There were two types of collocated samples. First are field splits of the same sample material, which are called QA duplicate analyses. QA duplicates were collected in a random manner and included a variety of geomorphic settings. Second are stratigraphic sections that were resampled because of high values after the initial sampling round or other reasons, which are called resamples. The collection of resamples tests the repeatability of the highest sample results. Because of the importance of plutonium-239,240, Appendix E-4.0 shows the relationship between 10 pairs of QA duplicate results and 6 pairs of resample results. The QA duplicates show less variability than the resamples, and the resamples also show a significant negative bias (second sample result tends to be much less than the first result), although the number of resampled layers is small and there is no reason to expect layers to have systematically lower plutonium concentrations in later sampling events. For the set of paired samples representing the greatest difference between the original analysis and the subsequent analysis (samples 04PU-96-0128 and 04PU-96-0145), the original sample represented part of a sediment layer that provided higher field alpha radiation measurements than an adjacent part of this layer, as discussed in Section 2.3.1.2. The difference between analytical results in these samples is therefore consistent with the field measurements. In summary, this evaluation of collocated samples suggests that there is significant variability in plutonium-239,240 concentration in sediment layers with the highest values, increasing the uncertainty in average concentrations in these layers. The apparent negative bias in the resamples also may suggest that the original sample results, which are the ones used in data assessment, represent conservative worst-case estimates of plutonium concentration.

3.3.2 Reach P-1

3.3.2.1 Plutonium Concentrations

All samples from the c1, c2, c2b, and f1 units in P-1 East, downstream from Acid Canyon, contain plutonium-239,240 concentrations above those measured in P-1 West upstream from Acid Canyon (0.043-0.075 pCi/g) (Table 3.3-1), indicating rapid mixing of sediment derived from Acid Canyon with sediment carried by floods from upstream parts of Pueblo Canyon.

TABLE 3.3-1

REACH P-1 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-1 West (Upstream of Acid Canyon)											
c2	PU-0016	0–8	0–20	Overbank	1	04PU-96-0123	0 (U)[c]	0.075	ms	ls	Full-suite sample
		0–8.5	0–21	Overbank	3	04PU-97-0081	0.004 (U)	0.057	ms	ls	Limited-suite sample
		8.5–14	21–35	Overbank	3	04PU-97-0082	0.016 (U)	0.046	vfs	sl	Limited-suite sample
		8.5–14	21–35	Overbank	3	04PU-97-0083	0 (U)	0.039	NA[d]	NA	QA duplicate
Acid Canyon											
c1	PU-0017	0–3	0–8	Channel	1	04PU-96-0124	0.059	12.593	cs	s	Full-suite sample
f1	PU-0119	0–3	0–8	Overbank	3	04PU-97-0079	0.045	13.7	fs	sl	Limited-suite sample
		6.5–11	16–28	Overbank	3	04PU-97-0084	0.0 (U)	2.33	ms	sl	Limited-suite sample
P-1 East (Downstream of Acid Canyon)											
c1	PU-0019	0–4	0–10	Channel	1	04PU-96-0126	0.028	6.297	cs	gs	Full-suite sample
c1	PU-0108	0–2	0–5	Channel	3	04PU-97-0093	-0.007 (U)	2.36	vcs	gs	
c1	PU-0109	0–2	0–5	Channel	3	04PU-97-0094	0.014 (U)	4.87	cs	gs	
c1	PU-0113	0–2	0–5	Channel	3	04PU-97-0098	0.029	5.36	vcs	gs	
c2	PU-0018	0–3	0–8	Overbank	1	04PU-96-0125	0.055	11.743	ms	ls	Full-suite sample
		4–10	10–25	Overbank	2	04PU-96-0149	0.064 (J)[e]	9.5 (J)	fs	ls	
		10–16	25–41	Overbank	2	04PU-96-0150	0.072 (J)	16 (J)	fs	sl	
c2	PU-0026	0–6	0–15	Overbank	2	04PU-96-0157	0.07 (J)	14 (J+)[f]	fs	sl	
		6–13	15–33	Overbank	2	04PU-96-0158	0.096 (J)	20 (J+)	csi	l	
		13–20	33–51	Overbank	2	04PU-96-0159	0.086 (J)	19 (J+)	fs	sl	
		20–25	51–64	Overbank	2	04PU-96-0160	0.075 (J)	15 (J)	vfs	sl	
		25–36	64–91	Overbank	2	04PU-96-0161	0.082 (J)	17 (J)	ms	ls	
		36–41	91–104	Overbank	2	04PU-96-0162	0.059 (J)	14 (J+)	vfs	l	

a. vcs = very coarse sand, cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt
b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel
c. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.
d. NA = not analyzed
e. J = The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.
f. J+ = The analyte was positively identified, and the reported value is an estimate and likely biased high.

TABLE 3.3-1 (continued)

REACH P-1 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-1 East (Downstream of Acid Canyon)											
c2	PU-0026	41–45	104–114	Overbank	2	04PU-96-0163	0.12	18 (J+)[c]	csi	l	
c2	PU-0104	0–10.5	0–27	Overbank	3	04PU-97-0085	0.088	16.1	ms	ls	
		10.5–18	27–46	Overbank	3	04PU-97-0086	0.185	31.5	vfs	sl	
		18–33.5	46–85	Overbank	3	04PU-97-0087	0.192	39	vfs	sl	
c2	PU-0105	21.5–27	55–69	Overbank	3	04PU-97-0088	0.69	11.2	cs	ls	
		27–30.5	69–77	Overbank	3	04PU-97-0089	0.033	6.87	ms	ls	
		30.5–34	77–86	Overbank	3	04PU-97-0090	0.046	10.5	vfs	sl	
		34–37.5	86–95	Overbank	3	04PU-97-0091	0.061	15.8	vfs	gsl	
c2	PU-0107	19.5–27.5	50–70	Overbank	3	04PU-97-0092	0.185	27.9	vfs	sl	
c2	PU-0110	19.5–31.5	50–80	Channel	3	04PU-97-0095	0.026 (U)[d]	4.8	cs	gs	
c2	PU-0111	33.5–45.5	85–115	Channel	3	04PU-97-0096	0.015 (U)	4.09	vcs	gs	
c2	PU-0114	0–4.5	0–12	Overbank	3	04PU-97-0099	0.029	8.11	vfs	sl	
		4.5–12	12–31	Overbank	3	04PU-97-0100	0.079	12.2	ms	gsl	
		12–27.5	30–70	Channel	3	04PU-97-0101	0.099	15.5	cs	sl	
c2	PU-0115	14–27.5	35–70	Channel	3	04PU-97-0102	0.043	8	vcs	gs	
c2b	PU-0020	0–11	0–28	Overbank	1	04PU-96-0127	0.078	18.102	vfs	sl	Full-suite sample
		0–4	0–10	Overbank	2	04PU-96-0139	0.031 (U)	15 (J)[e]	fs	sl	Resampled and split layer
		4–9	10–23	Overbank	2	04PU-96-0141	0.15 (U)	29 (J)	csi	sl	Resampled and split layer
		9–16	23–41	Overbank?	2	04PU-96-0142	0.15	25 (J)	cs	gs	
		16–21	41–53	Overbank	2	04PU-96-0143	0.34	55 (J)	vfs	sl	
		21–25	53–64	Overbank	2	04PU-96-0144	0.84	150 (J)	vfs	l	

a. vcs = very coarse sand, cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

c. J+ = The analyte was positively identified, and the reported value is an estimate and likely biased high.

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

e. J = The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.

TABLE 3.3-1 (continued)

REACH P-1 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-1 East (Downstream of Acid Canyon)											
c2b	PU-0020	25–30	64–76	Overbank	1	04PU-96-0128	2.078	502.01	fs	sl	Full-suite sample
		25–30	64–76	Overbank	2	04PU-96-0145	0.12	25 (J)[c]	vfs	l	Resampled layer
		32–36	81–91	Channel	2	04PU-96-0146	0.15	44 (J)	cs	gls	
c2b	PU-0025	0–4	0–10	Overbank	2	04PU-96-0151	0.15	30 (J)	ms	s	
		4–10	10–25	Overbank	2	04PU-96-0152	0.062 (J)	15 (J)	vfs	sl	
		10–18	25–46	Overbank	2	04PU-96-0153	0.11	18 (J+)[d]	fs	sl	
		18–26	46–66	Overbank	2	04PU-96-0154	0.67	86 (J+)	fs	sl	
		26–30	66–76	Overbank	2	04PU-96-0155	1.3	170 (J+)	ms	sl	
		30–36	76–91	Overbank	2	04PU-96-0156	1	240 (J+)	fs	sl	
		36–41	91–104	Overbank	2	04PU-96-0165	0.067 (J)	20 (J)	ms	sl	
		41–51	104–130	Channel	2	04PU-96-0166	0.034 (J)	6	cs	gs	
		51–63	130–160	Channel	2	04PU-96-0164	0.039 (J)	4.8 (J)	vcs	gs	
c2b	PU-0106	21.5–26.5	54–67	Overbank	3	04PU-97-0076	0.29	79.5	fs	sl	Limited-suite sample
		26.5–31.5	67–80	Overbank	3	04PU-97-0077	0.274	92.9	ms	sl	Limited-suite sample
		31.5–34.5	80–88	Overbank	3	04PU-97-0080	0.108	39	vfs	gsl	Limited-suite sample
f1	PU-0022	0–2	0–5	Overbank	1	04PU-96-0129	0.014	3.655	fs	ls	Full-suite sample
f1	PU-0112	0–5.5	0–14	Overbank	3	04PU-97-0097	0.037	9.92	ms	ls	
f1	PU-0116	0–10	0–25	Overbank	3	04PU-97-0104	0.098	23.8	csi	gsil	
f1	PU-0117	0–5	0–13	Overbank	3	04PU-97-0106	-0.011 (U)[e]	0.83	ms	gsl	
f1	PU-0120	0–5	0–13	Overbank	3	04PU-97-0103	0.141	32.7	fs	sl	
		5–16.5	13–42	Overbank	3	04PU-97-0105	0.001 (U)	0.49	ms	ls	
f1	PU-0122	0–6	0–15	Overbank	3	04PU-97-0109	0.01 (U)	1.67	cs	gls	
f2	PU-0121	0–4	0–10	Overbank	3	04PU-97-0107	-0.017 (U)	0.215	ms	gls	

a. vcs = very coarse sand, cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, sil = silt loam, g = ≥20% gravel

c. J = The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.

d. J+ = The analyte was positively identified, and the reported value is an estimate and likely biased high.

e. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

Plutonium-239,240 concentrations within reach P-1 are highest in a subsurface interval within the geographically small c2b geomorphic unit in P-1 East, below a depth of 40 cm, and all analyses greater than 40 pCi/g were obtained from this interval (Figures 2.3-3 and 3.3-1). Measured plutonium concentration varies greatly within this interval, ranging from 20 to 502 pCi/g in 10 samples, with an average of 143 pCi/g and a median of 90 pCi/g (Table 3.3-2). In comparison, texturally similar sediments within the widespread c2 unit and in the upper 40 cm of the c2b unit have a maximum of 39 pCi/g, an average of 18 pCi/g, and a median of 16 pCi/g plutonium in 25 samples. Overbank sediments on the active floodplains, f1, have plutonium concentrations that overlap with concentrations in the c2 unit, although the average concentration in the f1 unit (10 pCi/g) is less than in the c2 unit. These differences between the c2 unit and the f1 unit may indicate differences in sediment sources. Specifically, it is possible that the larger floods that overtopped the f1 surfaces had a larger percentage of sediment derived from upstream of Acid Canyon than the typical floods that deposited the c2 sediment, causing resultant deposits on the f1 surfaces to have lower levels of plutonium.

Channel facies samples from the c1, c2, and c2b units downstream from Acid Canyon have measured plutonium-239,240 concentration ranging from 2 to 44 pCi/g, consistently lower than associated overbank facies samples (Table 3.3-1). The median values for each unit are similar, 5.1 to 6.4 pCi/g, but maximum and average values increase from the c1 to the c2 and c2b units (Table 3.3-2), consistent with higher concentrations of plutonium occurring in older sediment deposits.

Because reach P-1 East includes the confluence with a major tributary to Pueblo Canyon, Walnut Canyon (Figure 2.1-1), the plutonium data were compared between sites upstream and downstream from the confluence to evaluate whether sediment contributed by Walnut Canyon may have resulted in significant dilution of plutonium concentrations. No difference in plutonium concentrations in the c1 or c2 channel facies sediment is apparent upstream and downstream of Walnut Canyon. However, the c2 overbank sediment and related c2b sediment (0 to 0.4 m interval) average about 25% higher upstream from Walnut Canyon, and all samples with plutonium-239,240 exceeding 20 pCi/g were collected upstream from Walnut Canyon. Thus, this comparison indicates that some dilution may occur at Walnut Canyon, although confidence in this interpretation is limited by the short sampling area (200 m in length) and the relatively small number of samples (nine samples) downstream from Walnut Canyon. In addition, there is considerable overlap in plutonium concentrations in the c2 overbank sediment between these two areas (Figure 3.3-2). For the purposes of this report, it is assumed that dilution by sediment from Walnut Canyon is minimal, and data from all of P-1 East are combined for calculating averages in this section and for extrapolating between P-1 and P-2 in Section 4.

One sample collected from a large f2 surface immediately downstream from the confluence of Acid Canyon and Pueblo Canyon yielded 0.215 pCi/g plutonium-239,240 (sample 04PU-97-0107), a value higher than samples from P-1 West and higher than background values but lower than any other sample in P-1 East. Although this analysis could indicate inundation of this surface by a large post-1942 flood carrying sediment with small concentrations of plutonium, a more likely interpretation may be local dispersion by wind or animals of small amounts of plutonium from the adjacent c2 unit.

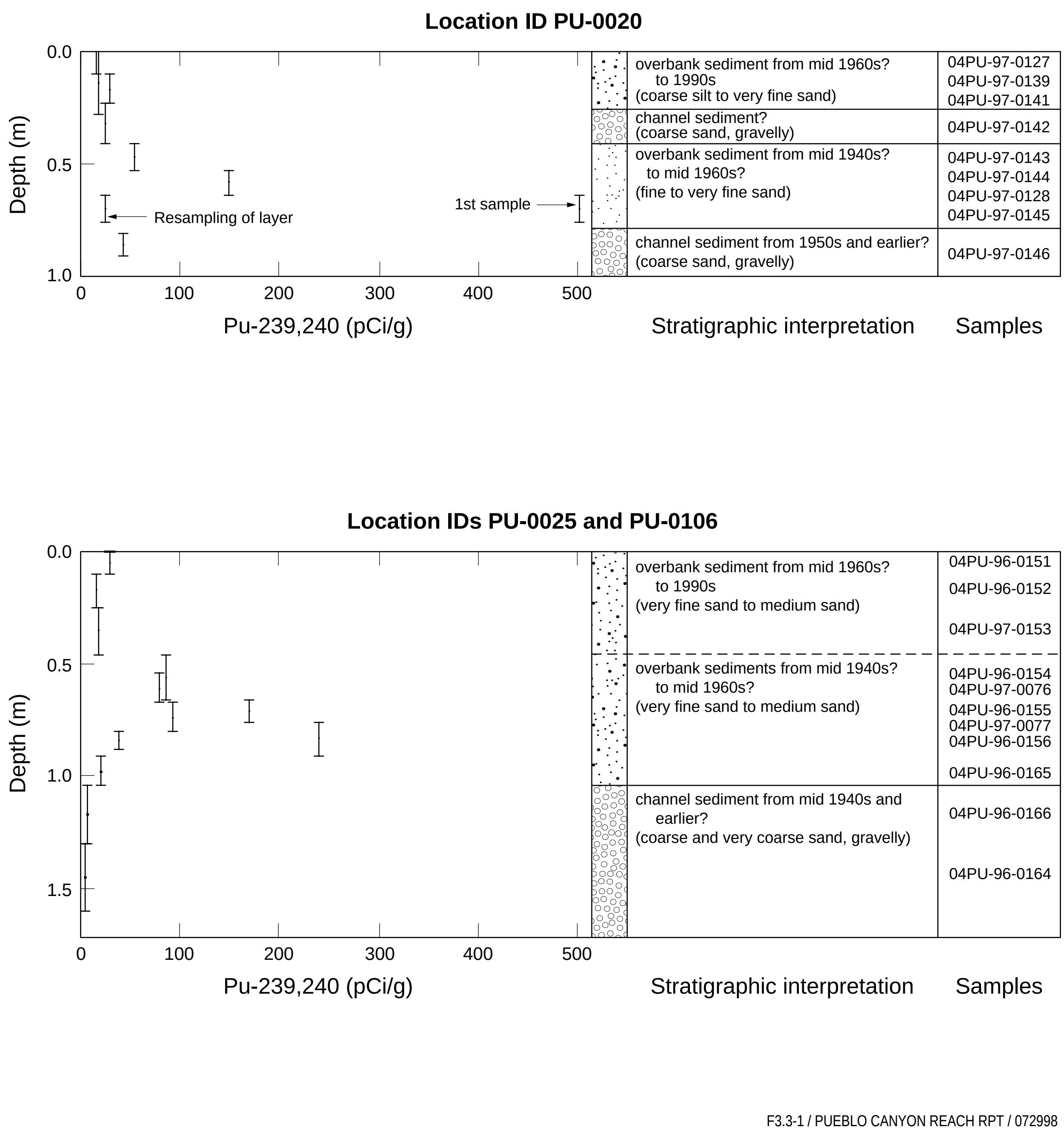


Figure 3.3-1. Depth variations in plutonium-239,240 concentration at sample sites in the c2b unit in reach P-1 East.

TABLE 3.3-2

SUMMARY OF BINNED PLUTONIUM ANALYSES IN REACH P-1

Geomorphic Unit and Sediment Facies	Summary Statistic	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Median Particle Size (mm)	Soil Texture[b]	Pu-239/238 ratio
P-1 West (Upstream of Acid Canyon)							
c2 overbank	average	0.004	0.058	fs	0.366	sl	15
	std. dev.	0.004	0.016				
	maximum	0.008	0.075				
	minimum	0.000	0.043				
	median	0.004	0.057				
	n	3	3				
Acid Canyon							
channel and overbank	average	0.035	9.5	ms	0.359	ls	275
	std. dev.	0.031	6.3				
	maximum	0.059	13.7				
	minimum	0.000	2.3				
	median	0.045	12.6				
	n	3	3				
P-1 East (Downstream of Acid Canyon)							
c1 channel	average	0.016	4.7	vcs	1.015	gs	295
	std. dev.	0.017	1.7				
	maximum	0.029	6.3				
	minimum	-0.007	2.4				
	median	0.021	5.1				
	n	4	4				
c2 overbank and c2b (0–0.4 m) overbank	average	0.12	17.6	fs	0.206	sl	151
	std. dev.	0.13	7.8				
	maximum	0.69	39.0				
	minimum	0.03	6.9				
	median	0.08	16.0				
	n	25	25				
c2 channel	average	0.046	8.1	cs	0.882	gs	177
	std. dev.	0.037	5.2				
	maximum	0.099	15.5				
	minimum	0.015	4.1				
	median	0.035	6.4				
	n	4	4				

a. vcs = very coarse sand, cs = coarse sand, ms = medium sand, fs = fine sand

b. sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

TABLE 3.3-2 (continued)

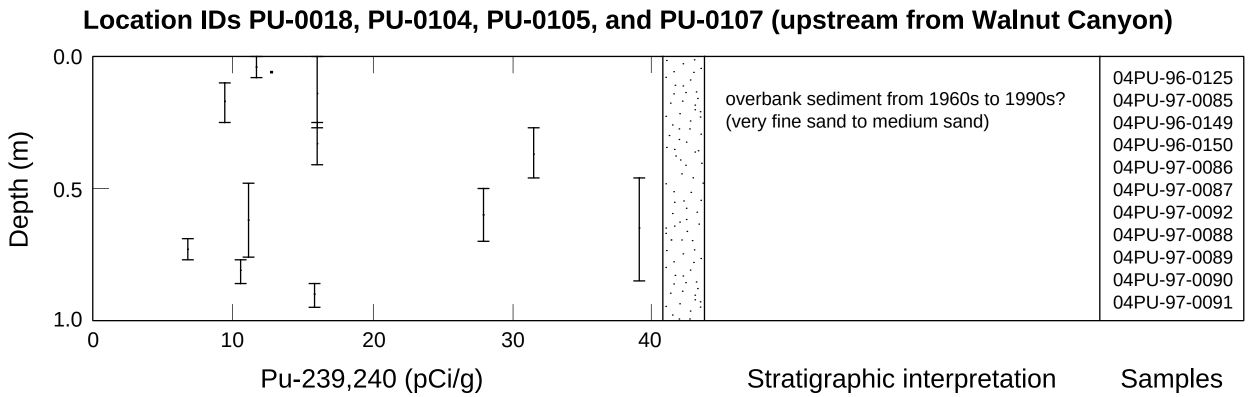
SUMMARY OF BINNED PLUTONIUM ANALYSES IN REACH P-1

Geomorphic Unit and Sediment Facies	Summary Statistic	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Median Particle Size (mm)	Soil Texture[b]	Pu-239/238 ratio
P-1 East (Downstream of Acid Canyon)							
c2b (0.4–0.9 m) overbank	average	0.69	143.4	fs	0.173	sl	208
	std. dev.	0.64	142.4				
	maximum	2.08	502.0				
	minimum	0.05	20.0				
	median	0.51	89.5				
	n	10	10				
c2b channel	average	0.074	18.3	cs	0.817	gs	246
	std. dev.	0.066	22.3				
	maximum	0.150	44.0				
	minimum	0.034	4.8				
	median	0.039	6.0				
	n	3	3				
f1 overbank (P-1 East)	average	0.041	10.4	fs	0.214	sl	252
	std. dev.	0.057	12.8				
	maximum	0.141	32.7				
	minimum	-0.011	0.5				
	median	0.014	3.7				
	n	7	7				
f2 overbank	average	-0.017	0.215	ms	0.365	gls	N.A.[c]
	n	1	1				

a. cs = coarse sand, ms = medium sand, fs = fine sand

b. sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

c. N.A. = not available



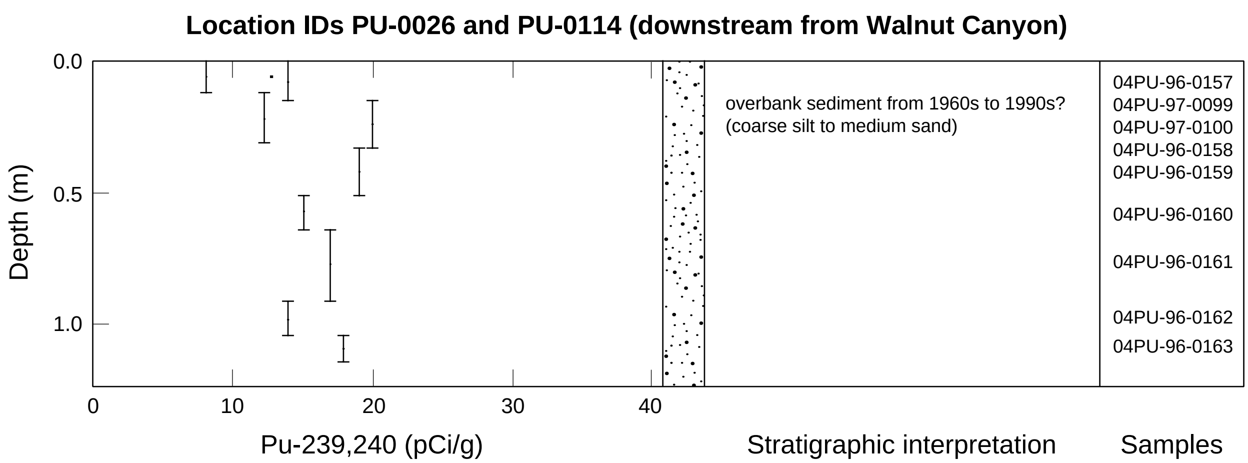


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Figure 3.3-2. Depth variations in plutonium-239,240 concentration in overbank facies sediment at sample sites in the c2 unit in reach P-1 East.

3.3.2.2 Age and Particle Size Relations

Age control for sampled sediment deposits is relatively imprecise in reach P-1 as compared with some downstream reaches, and as a result temporal trends in plutonium concentration are only partially defined in reach P-1. The highest concentrations of plutonium-239,240, in unit c2b, are from the lower part of the overbank sediments that bury the base of a tree dated at approximately 1923 AD (PUB-023, Table B1-1, Figure 2.3-3), suggesting that these sediments may date to early in the post-1942 period and perhaps be contemporaneous with the time of peak releases from TA-45. Above the layers with the highest plutonium concentrations in unit c2b, concentrations decrease with height (Figure 3.3-1), indicating a decrease over time. Plutonium concentrations at most c2 sample locations show no obvious trends with depth, although the highest concentrations were obtained from relatively deep samples (Figure 3.3-2).

Data on temporal trends in the supply of plutonium to P-1 are provided from samples collected from the environmental surveillance sampling station at Acid Weir that extend back to 1970, which are presumed to represent active channel samples (Figure 3.3-3). Although there is considerable scatter in these data, a decrease in plutonium concentrations is indicated, with average concentrations decreasing from 14.5 pCi/g in the 1970s to 10.1 pCi/g in the 1980s and 6.5 pCi/g in the 1990s. Thus, these data suggest that the concentration of plutonium in sediments transported from Acid Canyon into Pueblo Canyon has been decreasing during this time period.

Scatter plots of plutonium concentrations versus particle size in P-1 East indicate that plutonium concentration generally increases with decreasing particle size, although much variability exists in these relationships (Figure B3-1). At least part of this variability is undoubtedly due to variations in sediment age and sediment source. The deeper c2b overbank sediments have higher levels of plutonium than other samples with similar particle size characteristics, and the variability within these older sediments may in part record changes in effluent releases during the time period represented by these sediments. The f1 samples also show high variability, with plutonium concentrations often much less than other samples with similar silt and clay content, which is inferred to result from a larger part of the sediment in the f1 deposits being derived from sources upstream from Acid Canyon. Variability in plutonium concentration in c1 and c2 sediment samples with similar particle size characteristics may incorporate a combination of these factors, although general trends are still apparent within these data.

3.3.2.3 Plutonium Inventory

A total of approximately 82 mCi/km of plutonium-239,240 is estimated be stored within reach P-1 East. Most of the plutonium inventory, 82%, is estimated to be contained within relatively fine-grained overbank facies sediment, and only approximately 18% within the coarser-grained channel facies sediment (Table 3.3-3). Only approximately 5% of the plutonium is estimated to reside in the active channel. The largest portion of the total plutonium inventory occurs within overbank sediment of the widespread c2 unit, and lesser amounts within the areally restricted c2b unit and the large f1 unit. The c2 unit is estimated to contain approximately 52% of the total plutonium in P-1 East. Average thicknesses and volumes of all post-1942 sediment deposits in P-1 East may tend to be overestimated in this inventory because of the common large boulders that were not subtracted from the area of each unit, resulting in a possible overestimate of stored plutonium. In addition, the estimated area of the f1 unit may be too large because it was mapped conservatively to avoid underestimation of the extent of contamination, also potentially resulting in an overestimate of plutonium inventory.

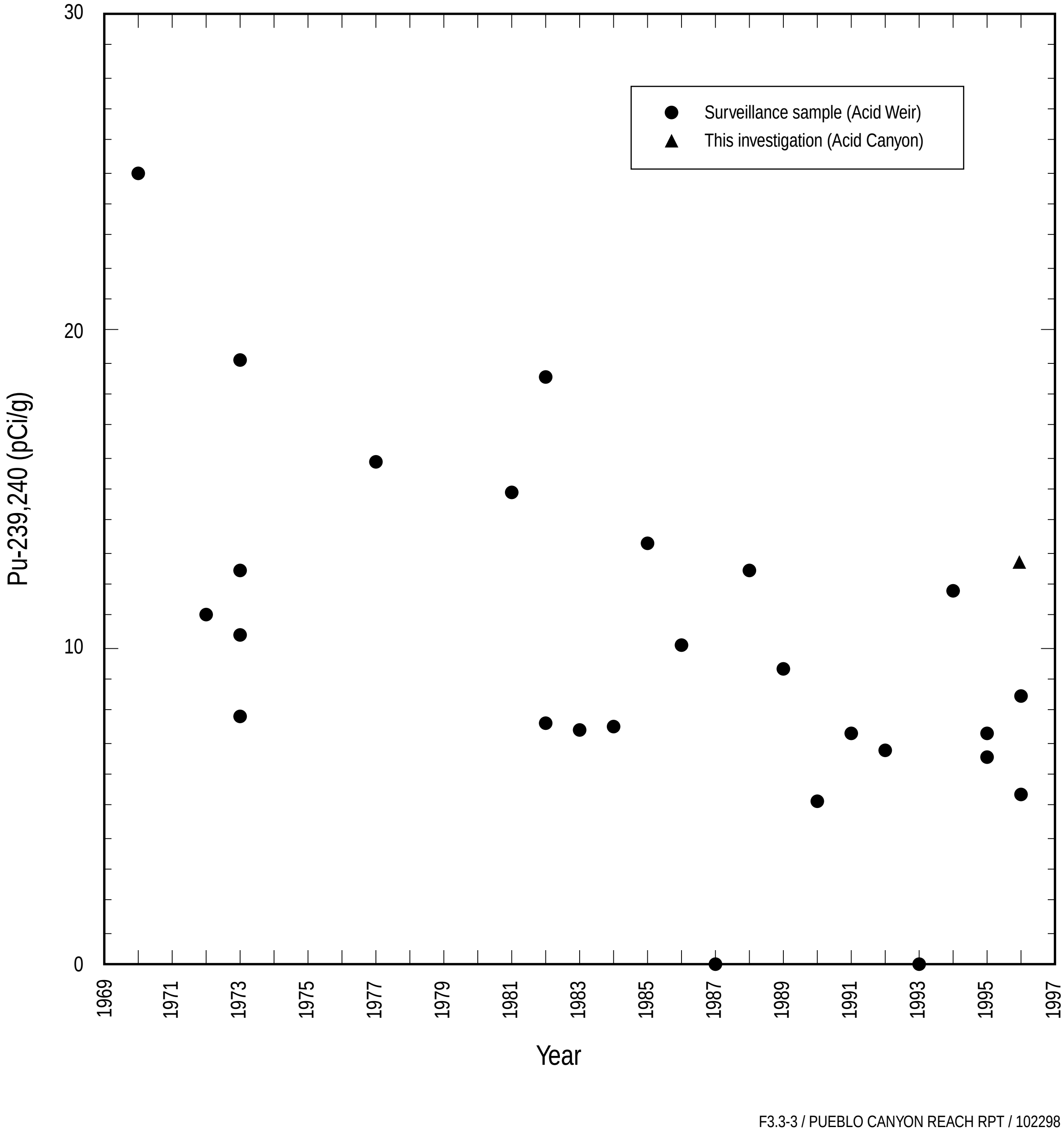


Figure 3.3-3. Relation of plutonium-239,240 concentration to age from active channel sediment samples collected in lower Acid Canyon.

TABLE 3.3-3

ESTIMATED PLUTONIUM INVENTORY IN REACH P-1

Sediment Facies	Geomorphic Unit	Section	Area (m^2)	Estimated Average Thickness (m)	Estimated Volume (m^3)	Estimated Fraction <2 mm	Estimated Density (g/cm^3)	Estimated Average Pu-239,240 Concentration (pCi/g)	Estimated Pu-239,240 Inventory (mCi)	Percent of Total Subreach Inventory	Percent Potentially Susceptible to Remobilization	Estimated Inventory Most Susceptible to Remobilization (mCi)	Percent of Total Subreach Inventory Susceptible to Remobilization
Reach P-1 East													
Channel	c1	All	1453	0.5	727	0.5	1.23	4.7	2.1	5%	100%	2.1	5%
Channel	c2	Lower	1389	0.5	695	0.5	1.23	8.1	3.5	8%	100%	3.5	8%
Channel	f1ll/c2?	Lower	857	0.25	214	0.5	1.23	8.1	1.1	3%	0%	0.0	0%
Channel	c2b	Lower	72	0.5	36	0.5	1.23	18.3	0.4	1%	100%	0.4	1%
Channel	fill/c2b?	Lower	178	0.25	45	0.5	1.23	18.3	0.5	1%	0%	0.0	0%
Subtotal					**1716**				**7.5**	**18%**		**6.0**	**14%**
Overbank	c2	Upper	1389	0.57	792	0.9	1.04	17.6	13.0	31%	100%	13.0	31%
Overbank	f1ll/c2?	Upper	857	0.28	240	0.9	1.04	17.6	4.0	9%	0%	0.0	0%
Overbank	c2b	Upper	72	0.4	29	0.9	1.04	17.6	0.5	1%	100%	0.5	1%
Overbank	c2b	Middle	72	0.5	36	0.9	1.04	143.4	4.8	11%	100%	4.8	11%
Overbank	fill/c2b?	Upper	178	0.2	36	0.9	1.04	17.6	0.6	1%	0%	0.0	0%
Overbank	fill/c2b?	Middle	178	0.25	45	0.9	1.04	143.4	6.0	14%	0%	0.0	0%
Overbank	f1	All	2398	0.27	647	0.85	1.04	10.4	6.0	14%	0%	0.0	0%
Overbank	f2	All	455	0.01	5	0.8	1.04	0.2	0.0	0%	0%	0.0	0%
Subtotal					**1829**				**34.8**	**82%**		**18.3**	**43%**
Total					**3545**				**42.3**	**100%**		**24.3**	**57%**

An additional major uncertainty in P-1 East is the amount of plutonium either buried by artificial fill associated with emplacement of the sewer line or possibly contained within fill material. A conservative overestimate of the area where fill may bury c2 and c2b units is included on the geomorphic map, and the potential plutonium inventory in these areas is calculated by assuming the same average plutonium concentrations as in the exposed c2 and c2b units but thicknesses only half that used for the c2 and c2b units (Table 3.3-3). These conservative calculations indicate that up to approximately 30% of the plutonium in P-1 East could be buried by fill, although the actual percentage may be much less.

3.3.3 Reach P-2

3.3.3.1 Plutonium Concentrations

Almost all samples from the c1, c1b, c2, c3, and f1 units in reach P-2 contain plutonium-239,240 above background values (Table 3.3-4). The only exceptions are two samples from f1 units in P-2 East, one at the surface and one from the subsurface (samples 04PU-97-0155 and 04PU-97-0240), that appear to record background levels and pre-1943 sediment deposits.

Plutonium-239,240 concentrations within reach P-2 are highest in overbank sediments in the c2 and f1 units in P-2 West, and three samples here yielded concentrations of 40 to 73 pCi/g; all other analyses in P-2 are less than 25 pCi/g. Two of the P-2 West samples with the highest plutonium concentration are from adjacent subsurface layers in the c2 unit at sample location PU-0130 (Figures 2.3-8 and 3.3-4), and the third is from a surface layer in the f1 unit at sample location PU-0161. Statistical parameters for plutonium concentration (maximum, minimum, mean, and median) are very similar between the c2 and f1 overbank sediments in P-2 West, and all overbank sediments in this subreach are considered to be part of one sedimentological, radiological, and statistical population. The overbank sediments range from 1 to 73 pCi/g plutonium-239,240, with a mean of 11 pCi/g and a median of 5 pCi/g (Table 3.3-5). The sediment with the highest plutonium concentrations apparently represent isolated pockets of relatively old post-1942 sediment that cannot be distinguished in the field from other c2 or f1 sediment and are thus not broken out in separate mapping units. Overbank sediment from most c2 locations have less than 10 pCi/g plutonium, and concentrations appear to increase slightly with depth (Figure 3.3-4). Channel facies sediment have lower levels of plutonium than overbank facies sediment, with means (and medians) of 1.2 (1.6) pCi/g for c1 and c1b samples and 3.8 (3.4) pCi/g for c2 samples (Table 3.3-5).

Plutonium concentrations are much lower in P-2 East than in P-2 West, which supports the hypothesis based on field observations that Kwage Canyon is a major sediment source (Section 2-1). Geomorphic and radiological evidence indicate that Kwage Canyon provides relatively large volumes of sediment with background levels of plutonium, which is mixed with sediment derived from farther west in Pueblo Canyon, thus significantly reducing plutonium concentrations. The maximum value of plutonium-239,240 in P-2 East, 8.1 pCi/g, is from an overbank sediment sample in the relatively old c3 unit (Figure 2.3-9), less than the mean for overbank sediments in P-2 West, and the mean value for the c3 unit is 5.3 pCi/g (Table 3.3-5). Overbank sediments in the more widespread c1b, c2, and f1 units of P-2 East have a maximum of 7.1 pCi/g plutonium-239,240, a mean of 2.2 pCi/g, and a median of 1.3 pCi/g. Plutonium concentrations in the c1b and c2 overbank facies sediment appear to increase slightly with depth, although concentrations are still relatively low at a depth of 1.5 m (Figure 3.3-5). Plutonium concentrations in coarse-grained channel sediment in the c1, c2, and c3 units in P-2 East are uniformly low as compared with upstream reaches, with a maximum of 1.1 pCi/g, a mean of 0.4 pCi/g, and a median of 0.3 pCi/g (Table 3.3-5) and show no change with depths down to 1.6 m (Figure 3.3-6).

TABLE 3.3-4

REACH P-2 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-2 West (Vicinity of Test Well 2)											
c1	PU-0132	0–2	0–5	Channel	1	04PU-97-0150	-0.009 (U)[c]	1.56	cs	s	
c1b	PU-0129	0–10	0–25	Channel	1	04PU-97-0141	0.002 (U)	1.64	cs	gs	
		0–10	0–25	Channel	2	04PU-97-0213	NA[d]	NA	NA	NA	Layer resampled for limited suite
		10–20	25–51	Overbank	1	04PU-97-0142	0.022	3.84	fs	sl	
		20–28	51–71	Channel	1	04PU-97-0143	-0.004 (U)	0.469	vcs	gs	
c2	PU-0124	0–9	0–23	Overbank	1	04PU-97-0125	0.023 (U)	4.13	fs	sl	
		9–14	23–35	Overbank	1	04PU-97-0126	0.113	23.2	fs	gsl	
		9–14	23–35	Overbank	1	04PU-97-0127	0.088	21.9	NA	NA	QA duplicate
		16–36	41–91	Channel	1	04PU-97-0128	0.003 (U)	1.65	cs	gs	
c2	PU-0127	0–11	0–28	Overbank	1	04PU-97-0133	-0.006 (U)	1.92	ms	sl	
		17.5–23	44–59	Overbank	1	04PU-97-0134	0.006 (U)	4.9	vfs	sl	
		17.5–23	44–59	Overbank	1	04PU-97-0135	0.007 (U)	4.94	NA	NA	QA duplicate
		25.5–33.5	65–85	Channel	1	04PU-97-0136	0.019 (U)	4.86	cs	gs	
c2	PU-0130	0–9.5	0–24	Overbank	1	04PU-97-0144	0.027	7.67	vfs	sl	
		9.5–13.5	24–34	Overbank	1	04PU-97-0145	0.043	12.9	vfs	sl	
		13.5–16.5	34–42	Overbank	1	04PU-97-0146	0.137	40	fs	ls	
		16.5–19.5	42–50	Overbank	1	04PU-97-0147	0.231	73.4	vfs	sl	
		16.5–19.5	42–50	Overbank	2	04PU-97-0212	NA	NA	NA	NA	Layer resampled for limited suite
		20.5–32.5	52–82	Channel	1	04PU-97-0148	0.014	6.85	cs	gs	
c2	PU-0158	0–9	0–23	Overbank	2	04PU-97-0209	0.0242 (U)	2.74	vfs	sl	Limited-suite sample
		11–17	28–43	Overbank	2	04PU-97-0210	0.017 (U)	3.99	vfs	sl	Limited-suite sample
		18.5–20.5	47–52	Overbank	2	04PU-97-0215	0.019 (U)	4.48	vfs	sl	

a. vcs = very coarse sand, cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand

b. sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

c. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

d. NA = not analyzed

TABLE 3.3-4 (continued)

REACH P-2 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a,b]	Soil Texture[b,c]	Notes
P-2 West (Vicinity of Test Well 2)											
c2	PU-0158	32–40	81–102	Channel	2	04PU-97-0211	0.0232	1.86	cs	gs	Limited-suite sample
c2	PU-0160	0–4.5	0–12	Overbank	2	04PU-97-0216	0.0006 (U)[d]	2.1	fs	sl	
		4.5–14	12–36	Overbank	2	04PU-97-0217	0.029 (U)	3.95	vfs	sl	
		14–21.5	36–54	Overbank	2	04PU-97-0218	0.0134 (U)	5.21	vfs	sl	
c2	PU-0162	0–9	0–23	Overbank	2	04PU-97-0221	0.0189 (U)	2.73	fs	sl	
		11–16.5	28–42	Overbank	2	04PU-97-0222	0.0227	4.72	vfs	sl	
		22.5–29	57–74	Overbank	2	04PU-97-0223	0.031 (U)	6.05	fs	ls	
f1	PU-0125	0–8	0–20	Overbank	1	04PU-97-0129	0.048	5.94	fs	sl	
		8–12	20–31	Overbank	1	04PU-97-0130	0.031	5.72	fs	sl	
f1	PU-0126	0–3	0–8	Overbank	1	04PU-97-0131	0.037	5.69	vfs	sl	
		0–3	0–8	Overbank	2	04PU-97-0214	NA[e]	NA	NA	NA	Layer resampled for limited suite
		4.5–12	12–30	Overbank	1	04PU-97-0132	0.032 (U)	12.6	fs	sl	
f1	PU-0128	0–5	0–13	Overbank	1	04PU-97-0137	0.037 (U)	5.26	ms	ls	
		5–10.5	13–27	Overbank	1	04PU-97-0138	0.021 (U)	4.36	fs	ls	
		10.5–16	27–40	Overbank	1	04PU-97-0139	0.06	9.7	(ms)	(sl)	
		16–19	40–48	Overbank	1	04PU-97-0140	0.083	12.4	ms	ls	
f1	PU-0131	0–16.5	0–42	Overbank	1	04PU-97-0149	0.053	11.1	fs	sl	
		17.5–23	45–59	Overbank	2	04PU-97-0220	0.0035 (U)	1.313	fs	ls	
f1	PU-0133	0–6.5	0–16	Overbank	1	04PU-97-0151	0.012 (U)	2.77	ms	ls	
		6.5–14	16–35	Overbank	1	04PU-97-0152	0.017 (U)	5.36	fs	ls	
f1	PU-0159	0–8.5	0–21	Overbank	2	04PU-97-0241	0.048	19.1	ms	sl	Limited-suite sample

a. cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand

b. No particle size data are available for 15 P-2 samples that were lost during shipping. Particle size characteristics for these samples are estimated from field notes and are shown in ( ).

c. sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

e. NA = not analyzed

TABLE 3.3-4 (continued)

REACH P-2 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a,b]	Soil Texture[b,c]	Notes
P-2 West (Vicinity of Test Well 2)											
f1	PU-0161	0–5	0–13	Overbank	2	04PU-97-0242	0.195	47.3	csi	sil	Limited-suite sample
f1	PU-0161	5–9	13–23	Overbank	2	04PU-97-0219	0.0187 (U)[d]	13.27	vfs	l	
P-2 East (Downstream from Kwage Canyon)											
c1	PU-0134	0–2	0–5	Channel	1	04PU-97-0153	-0.007 (U)	0.406	(cs)	(s)	
c1	PU-0174	52–56	130–145	Channel	3	04PU-98-0023	0 (U)	0.19	cs	s	
		59–63	150–160	Channel	3	04PU-98-0024	0.002 (U)	0.374	cs	ls	
Qbo	PU-0174	83–88	210–225	Tuff	3	04PU-98-0025	-0.001 (U)	0.001 (U)	NA[e]	NA	Otowi Member Bandelier Tuff
		95–99	240–250	Tuff	3	04PU-98-0026	0.001 (U)	0.002 (U)	NA	NA	Otowi Member Bandelier Tuff
c1b	PU-0138	0–5	0–13	Overbank	1	04PU-97-0164	0.008 (U)	2.02	(ms)	(sl)	
		16.5–36	42–92	Channel	1	04PU-97-0165	0.002 (U)	1.11	(cs)	(s)	
c2	PU-0137	0–7.5	0–19	Overbank	1	04PU-97-0159	-0.01 (U)	1.81	fs	sl	
		7.5–14.5	19–37	Overbank	1	04PU-97-0160	-0.014 (U)	0.492	vfs	sl	
		17.5–22.5	45–57	Overbank	1	04PU-97-0161	-0.005 (U)	0.194	vfs	sl	
		25–32.5	63–83	Overbank	1	04PU-97-0162	0.008 (U)	1.1	(vfs)	(sl)	
		41.5–48	106–122	Overbank	1	04PU-97-0163	-0.002 (U)	1.14	csi	sil	
c2	PU-0140	0–10	0–25	Overbank	1	04PU-97-0169	0.012 (U)	1.14	(ms)	(ls)	
		10–17	25–43	Overbank	1	04PU-97-0170	-0.001 (U)	0.468	(ms)	(sl)	
		10–17	25–43	Overbank	1	04PU-97-0171	0.001 (U)	0.582	NA	NA	QA duplicate
		17–22.5	43–57	Overbank	1	04PU-97-0172	-0.005 (U)	2.19	(vfs)	(sl)	
		22.5–33.5	57–85	Overbank?	1	04PU-97-0173	0.028	3.42	(ms)	(gls)	

a. cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. No particle size data are available for 15 P-2 samples that were lost during shipping. Particle size characteristics for these samples are estimated from field notes and are shown in ( ).

c. l = loam, sl = sandy loam, ls = loamy sand, s = sand, sil = silt loam, g = ≥20% gravel

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

e. NA = not analyzed

TABLE 3.3-4 (continued)

REACH P-2 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a,b]	Soil Texture[b,c]	Notes
P-2 East (Downstream from Kwage Canyon)											
c2	PU-0140	33.5–43.5	85–110	Overbank	1	04PU-97-0174	0.024 (U)[d]	5.59	csi	l	
		43.5–52	110–132	Overbank	1	04PU-97-0175	0.046 (U)	4.49	(fs)	(sl)	
c2	PU-0140	52–58.5	132–149	Overbank	2	04PU-97-0239	0.072	6.92	vfs	gsl	
c2	PU-0164	7–12	18–31	Channel	2	04PU-97-0233	-0.003 (U)	0.128	cs	s	
		21.5–30.5	55–77	Channel	2	04PU-97-0234	-0.0047 (U)	0.131	cs	s	
		38–48	97–122	Channel	2	04PU-97-0235	-0.0075 (U)	0.1	cs	s	
c3	PU-0136	0–3	0–8	Overbank	1	04PU-97-0156	0.009 (U)	5.71	csi	sl	
		3–6	8–15	Overbank	1	04PU-97-0157	-0.008 (U)	0.362	vfs	sl	
		6–9	15–23	Overbank	1	04PU-97-0158	0.032	7.11	ms	sl	
		9–14	23–36	Overbank	2	04PU-97-0236	0.028 (U)	8.07	ms	ls	
		15–20.5	38–52	Channel	2	04PU-97-0237	-0.001 (U)	0.576	cs	s	
f1	PU-0135	0–3	0–8	Overbank	1	04PU-97-0154	0.015 (U)	0.713	(fs)	(sl)	
		3–10	8–25	Overbank	1	04PU-97-0155	0.006 (U)	0.076	(fs)	(sl)	Background?
f1	PU-0139	0–6	0–15	Overbank	1	04PU-97-0166	0.023 (U)	7.06	(fs)	(sl)	
		6–11.5	15–29	Overbank	1	04PU-97-0167	0.004 (U)	1.33	(csi)	(sl)	
		11.5–15.5	29–39	Overbank	1	04PU-97-0168	0 (U)	3.66	(csi)	(sl)	
		15.5–23.5	39–60	Overbank	2	04PU-97-0238	0.022 (U)	2.09	ms	gsl	
f1	PU-0163	0–5	0–13	Overbank	2	04PU-97-0231	-0.0018 (U)	0.225	fs	sl	
		0–5	0–13	Overbank	2	04PU-97-0232	-0.0065 (U)	0.251	NA[e]	NA	QA duplicate
f1?	PU-0165	0–3.5	0–9	Overbank	2	04PU-97-0240	0.0101 (U)	0.04	csi	l	Background?

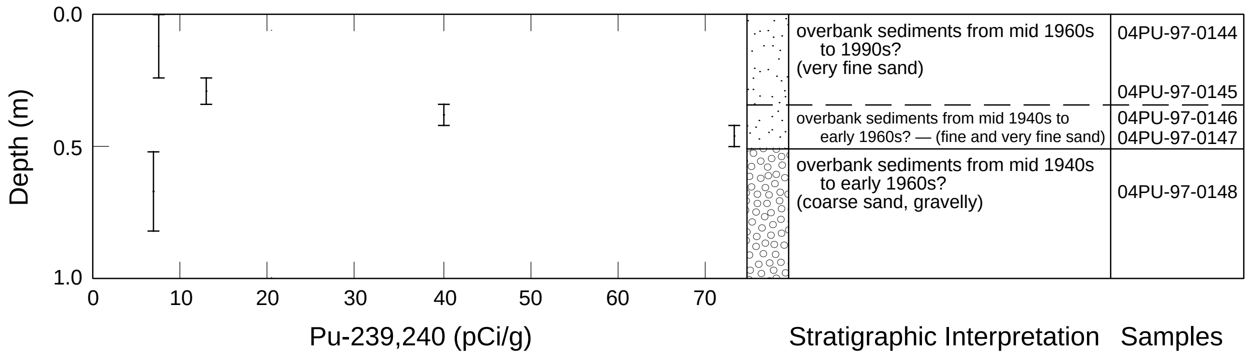
a. cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

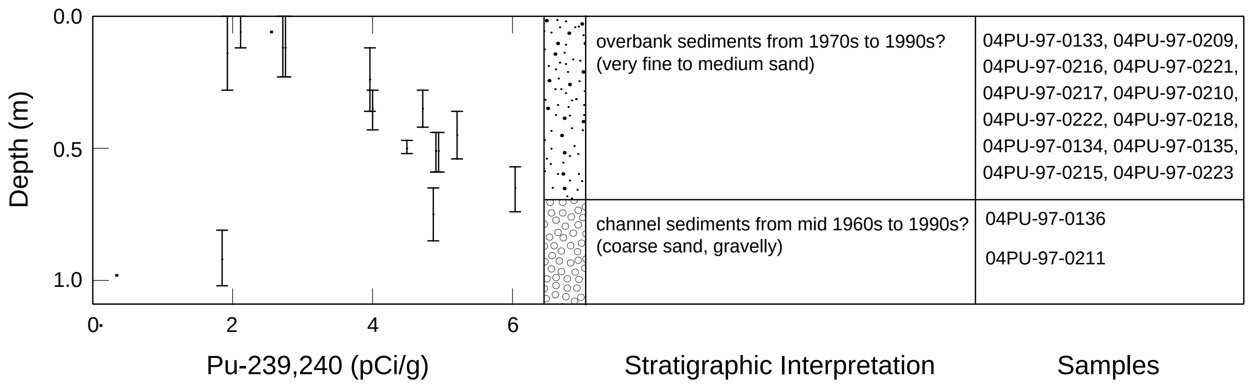
b. No particle size data are available for 15 P-2 samples that were lost during shipping. Particle size characteristics for these samples are estimated from field notes and are shown in ( ).

c. l = loam, sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

e. NA = not analyzed





F3.3-4 / PUEBLO CANYON REACH RPT / 071798

Figure 3.3-4. Depth variations in plutonium-239,240 concentration at sample sites in the c2 unit in reach P-2 West.

TABLE 3.3-5

SUMMARY OF BINNED PLUTONIUM ANALYSES IN REACH P-2

Geomorphic Unit and Sediment Facies	Summary Statistic	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Median Particle Size (mm)	Soil Texture[b]	Pu-239/238 ratio
P-2 West (Vicinity of Test Well 2)							
c1, c1b channel	average	-0.004	1.223	cs	0.832	gs	N.A.[c]
	std. dev.	0.006	0.654				
	maximum	0.002	1.640				
	minimum	-0.009	0.469				
	median	-0.004	1.560				
	n	3	3				
c2 channel	average	0.015	3.805	cs	0.775	gs	257
	std. dev.	0.009	2.504				
	maximum	0.023	6.850				
	minimum	0.003	1.650				
	median	0.017	3.360				
	n	4	4				
c1b, c2, f1 overbank	average	0.044	11.206	fs	0.129	sl	252
	std. dev.	0.053	15.121				
	maximum	0.231	73.400				
	minimum	-0.006	1.313				
	median	0.027	5.360				
	n	33	33				
P-2 East (Downstream from Kwage Canyon)							
c1, c1b, c2, c3 channel	average	-0.002	0.377	cs	0.687	s	N.A.
	std. dev.	0.004	0.341				
	maximum	0.002	1.110				
	minimum	-0.008	0.100				
	median	-0.002	0.282				
	n	8	8				
c1b, c2, f1 overbank	average	0.012	2.424	vfs	0.085	sl	206
	std. dev.	0.021	2.183				
	maximum	0.072	7.060				
	minimum	-0.014	0.194				
	median	0.008	1.810				
	n	19	19				
c3 overbank	average	0.015	5.313	vfs	0.095	sl	348
	std. dev.	0.018	3.440				
	maximum	0.032	8.070				
	minimum	-0.008	0.362				
	median	0.019	6.410				
	n	4	4				
Background[d]	average	0.008	0.058	vfs	0.058	l	7
	std. dev.	0.003	0.025				
	maximum	0.010	0.076				
	minimum	0.006	0.040				
	median	0.008	0.058				
	n	2	2				
Qbo	average	0.000	0.002	N.A.	N.A.	N.A.	N.A.
	std. dev.	0.001	0.001				
	maximum	0.001	0.002				
	minimum	-0.001	0.001				
	median	0.000	0.002				
	n	2	2				

a. cs = coarse sand, fs = fine sand, vfs = very fine sand
b. l = loam, sl = sandy loam, s = sand, g = ≥20% gravel
c. N.A. = not available
d. Samples inferred to represent background values are f1 layers with <0.08 pCi/g Pu-239,240

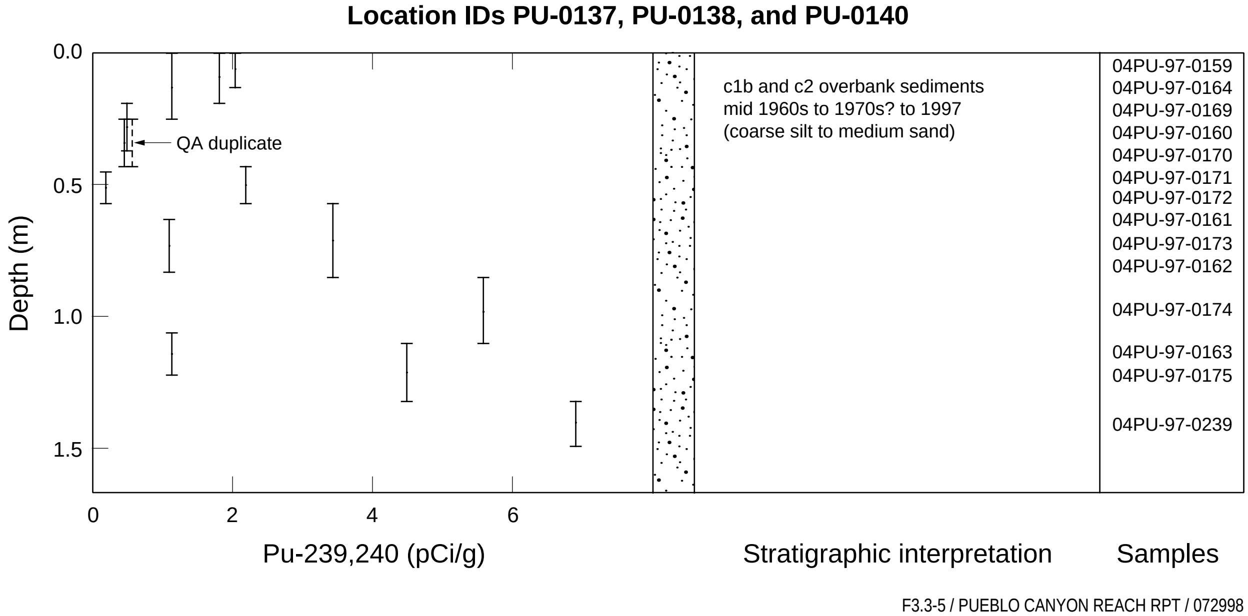


Figure 3.3-5. **Depth variations in plutonium-239,240 concentration in c1b and c2 overbank facies sediment samples in reach P-2 East.**

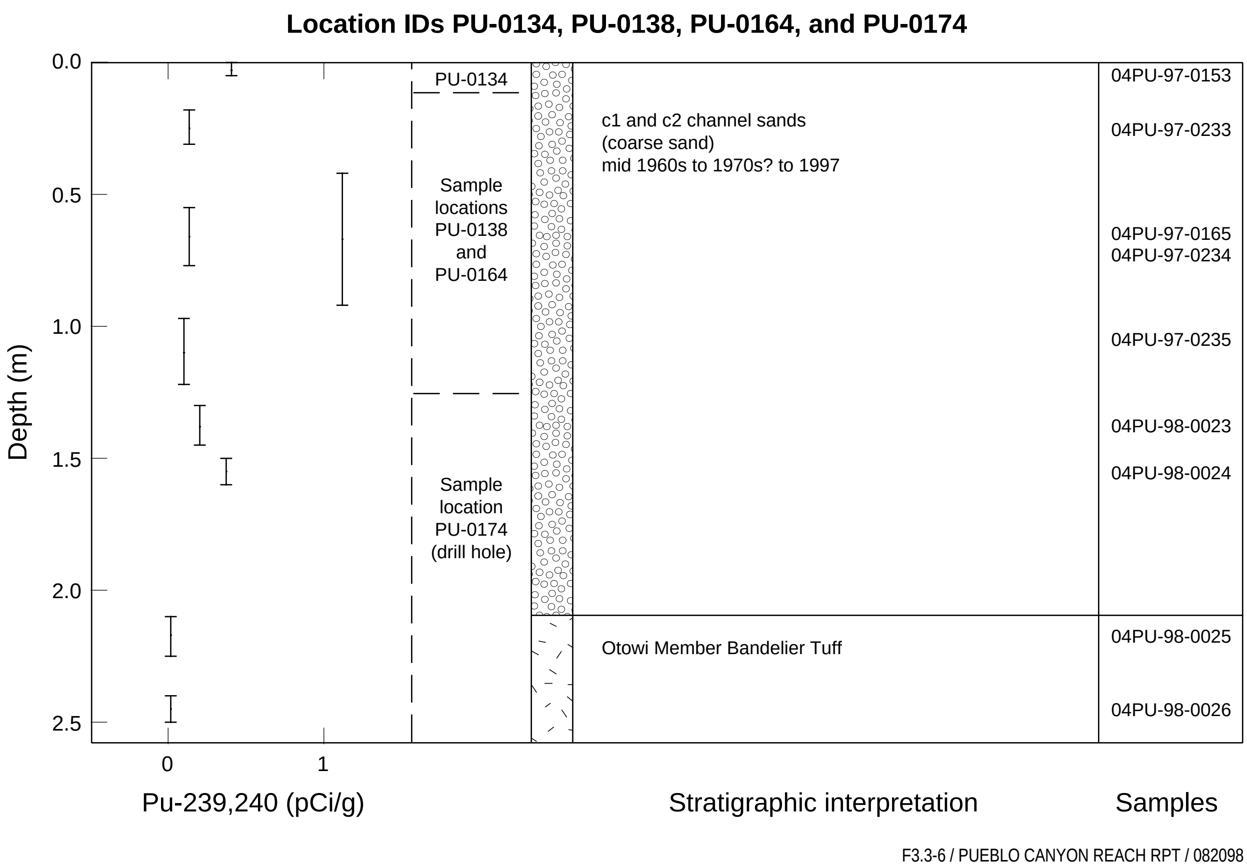


Figure 3.3-6. **Depth variations in plutonium-239,240 concentration in c1, c1b, and c2 channel facies sediment samples and tuff samples in reach P-2 East.**

Despite the statistical differences seen between plutonium concentrations in overbank sediment in P-2 West and P-2 East, other evidence suggests that many of the c2 overbank samples from these two subreaches may represent deposits from the same floods without significant dilution by sediment from Kwage Canyon. This interpretation is based on the similarity in both the depth trends and the plutonium concentrations between many c2 overbank facies sediment samples in these subreaches (Figures 3.3-4 and 3.3-5). These conflicting interpretations may be explained by differences in the relative supply of sediment from Kwage Canyon and upper Pueblo Canyon in different flood events. Specifically, if Kwage Canyon is not flooding at the same time as Pueblo Canyon, resultant sediment deposits upstream and downstream from the confluence may have similar concentrations of plutonium. In contrast, if both canyons are flooding then the sediment supplied from Kwage Canyon will result in dilution of plutonium.

Two samples of tuff from a depth of 2.1 to 2.5 m immediately below the alluvium at a drill hole through the c1 unit in P-2 East (sample location PU-0174, Figure 3.3-6) were submitted for plutonium analyses to determine if significant amounts of plutonium had been transported vertically from the alluvium into the substrate. The analyses indicated that plutonium is below the detection limit in these samples (samples 04PU-98-0025 and 04PU-98-0026, Table 3.3-4) and that the vertical extent of plutonium is limited to the full thickness of the alluvium here.

3.3.3.2 Age and Particle Size Relations

Most of the post-1942 sediments in both P-2 West and P-2 East are inferred to date from the mid 1960s or later based on tree-ring dating, aerial photograph interpretation, and comparison with sediments in P-4 with better age control (Section 3.3.5.2), and hence to postdate the last effluent releases from TA-45. For example, tree-ring dating indicates that overbank sediments postdate 1963 at one f1 sample location in P-2 West (PU-0125, trees PUB-005 and PUB-006, Table B1-1) where plutonium concentrations are typical for this subreach, and that no sediment was deposited at this location between 1937 and 1963. Similarly, overbank sediments at a f1 sample location in P-2 East (PU-0139, tree PUB-002, Table B1-1), with typical plutonium concentrations, postdate 1962. Much of the sampled c2 sediments in P-2 West are also inferred to postdate emplacement of the sewer line in the early 1960s (Figure 2.3-8). Slight decreases in plutonium concentration during the time represented by most of the c2 overbank sediments in both subreaches are indicated by the increases in plutonium with depth in Figures 3.3-4 and 3.3-5.

Local areas containing early post-1942 sediments in P-2 East are indicated by examination of aerial photographs and by tree-ring dating; these are the areas where the highest plutonium concentrations are found in reach P-4 (Section 3.3.5.2), but plutonium concentrations in these areas in P-2 East are relatively low. Sampled c3 channel sands at location PU-0136 were deposited between 1942 and 1952, based on examination of aerial photographs (Figure 2.3-10), tree-ring dating (tree PUB-001, Table B1-1, Figure 2.3-9), and the presence of plutonium above the background value, yet plutonium is present only at a concentration of 0.576 pCi/g (sample 04PU-97-0136). This low concentration could indicate either deposition very early in the post-1942 period, when only small amount of plutonium had been transported downstream from Acid Canyon, or the dominance of sediment from Kwage Canyon in this deposit.

Additional data on potential variations in plutonium concentration with age in P-2 are provided by samples collected from the environmental surveillance sampling station Pueblo 2 (originally called “Pueblo at TW 2”) in P-2 West that extend back to 1970, presumed to represent active channel samples (Figure 3.3-7). No trend over time is apparent within this period, and instead these data show large amounts of variability. The average of these data, 2.1 pCi/g, is similar to the average of the channel facies sediment from the c1 and c2 units in this investigation, 2.7 pCi/g.

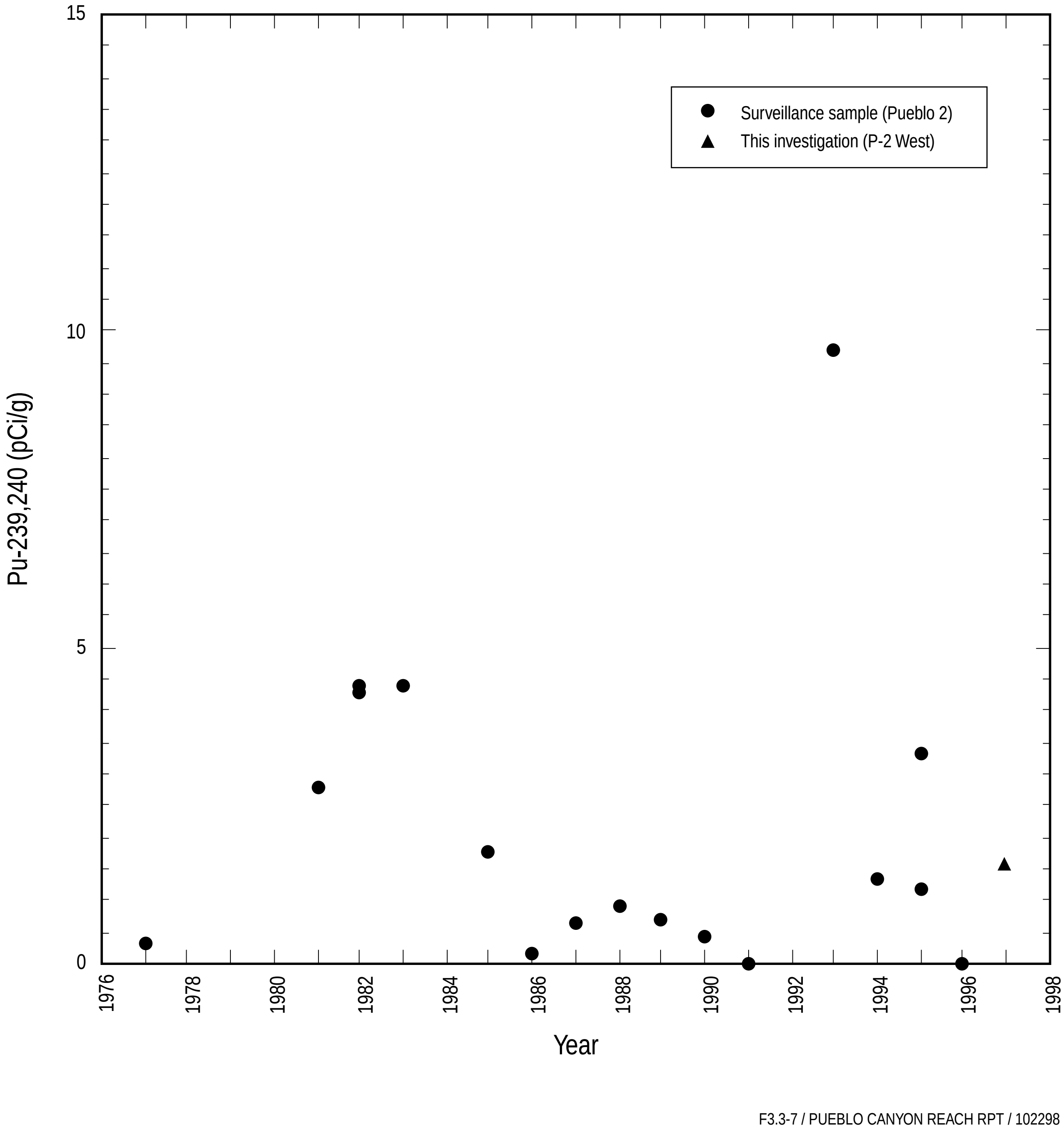


Figure 3.3-7. Relation of plutonium-239,240 concentration to age from active channel sediment samples collected in reach P-2 West.

Scatter plots showing particle size and plutonium data from P-2 sediment samples indicate general trends of increasing levels of plutonium with decreasing particle size and also help group samples into different age packages (Figure B3-2). The sample with the highest plutonium concentration in P-2 and an adjacent layer, from subsurface c2 overbank samples in P-2 West (location PU-0130), have exceptionally high plutonium levels relative to other samples with similar particle size characteristics and are inferred to record isolated pockets of sediment from the early post-1942 period. Notably, the sample with the second highest plutonium concentration in P-2 West (47 pCi/g in f1 at location PU-0161) is a surface sample that has the highest content of clay-sized particles (12.5%) and silt plus clay content (67%) in this subreach, suggesting that the relatively high plutonium level results from deposition of an exceptionally fine-grained layer and not from the presence of relatively old (pre-1962) sediment at this location.

An examination of plutonium and particle size data for reach P-2 East (Figure B3-2), particularly data on the percentage of clay-sized particles, indicates that most of the c3 overbank samples (location PU-0136) are closely related to the deepest c2 overbank samples from location PU-0140 (85 to 149 cm deep). These samples contain the highest levels of plutonium in P-2 East, although the levels are relatively low (<10 pCi/g). The similarity in these c2 and c3 samples suggests that they are closely related in age despite having a height difference of 1 to 1.5 m relative to the present channel, and that they span the time during which the channel incised 1.5 to 2 m from the c3 surface to the base of the c2 unit (Figure 2.3-9).

3.3.3.3 Plutonium Inventory

The amount and geomorphic distribution of the plutonium-239,240 inventory varies between P-2 West and P-2 East, associated with the changes in sizes and thicknesses of geomorphic units and associated plutonium levels downstream of Kwage Canyon.

P-2 West is similar to P-1 East in having most of the estimated plutonium inventory, 76%, contained within relatively fine-grained overbank facies sediment (Table 3.3-6). Similar percentages are estimated to occur within overbank sediments of the c2 unit close to the active channel, 31%, and the f1 unit farther from the channel, 36%. However, the estimated area and associated inventory in the f1 unit may be too large because it was mapped conservatively to avoid underestimating the extent of contamination. The most important unit for storage of plutonium in P-2 West is the c2 unit, containing an estimated 48% of the total inventory. Approximately 10% of the plutonium is estimated to reside in the active channel, c1, and in the closely associated c1b unit. The total estimated plutonium inventory in P-2 West, approximately 79 mCi/km, is very similar to that in P-1 East.

P-2 East has a much larger estimated volume of post-1942 sediment than P-2 West, but because of the much lower plutonium concentrations the total plutonium inventory is less (Table 3.3-6), estimated at 37 mCi/km. This constitutes the lowest amount of plutonium in Pueblo Canyon downstream from Acid Canyon, although it is only slightly less than that estimated to be stored in P-3 West (Section 3.3.4.3). The largest percentage of the plutonium in P-2 East, 57%, is estimated to be stored within overbank sediments, although the channel facies sediment is more important in P-2 East than in upstream reaches. The most important storage sites for plutonium in P-2 East are the c2 overbank sediments, estimated at 38% of the total, the c2 channel sediments, 26%, the c1 channel sediments, 15%, and the f1 overbank sediments, 12%.

TABLE 3.3-6

ESTIMATED PLUTONIUM INVENTORY IN REACH P-2

Sediment Facies	Geomorphic Unit	Section	Area (m^2)	Estimated Average Thickness (m)	Estimated Volume (m^3)	Estimated Fraction <2 mm	Estimated Density (g/cm^3)	Estimated Average Pu-239,240 Concentration (pCi/g)	Estimated Pu-239,240 Inventory (mCi)	Percent of Total Subreach Inventory	Percent Potentially Susceptible to Remobilization	Estimated Inventory Most Susceptible to Remobilization (mCi)	Percent of Total Subreach Inventory Susceptible to Remobilization
P-2 West (Vicinity of TW-2)													
Channel	c1	All	1374	1.0	1374	0.5	1.23	1.22	1.0	3%	100%	1.0	3%
Channel	c1b	Lower	1726	1.0	1726	0.5	1.23	1.22	1.3	3%	100%	1.3	3%
Channel	c2	Lower	2880	1.0	2880	0.5	1.23	3.81	6.7	17%	100%	6.7	17%
Channel	c3	Lower	198	1.0	198	0.5	1.23	3.81	0.5	1%	100%	0.5	1%
Subtotal					**6178**				**9.5**	**24%**		**9.5**	**24%**
Overbank	c1b	Upper	1726	0.1	173	0.85	1.04	11.21	1.7	4%	100%	1.7	4%
Overbank	c2	Upper	2880	0.41	1181	0.92	1.04	11.21	12.7	31%	100%	12.7	31%
Overbank	c3	Upper	198	0.63	125	0.92	1.04	11.21	1.3	3%	100%	1.3	3%
Overbank	f1	All	5044	0.27	1362	0.92	1.04	11.21	14.6	36%	0%	0.0	0%
Overbank	f2	All	863	0.05	43	0.92	1.04	11.21	0.5	1%	0%	0.0	0%
Subtotal					**2883**				**30.8**	**76%**		**15.7**	**39%**
Total					**9061**				**40.3**	**100%**		**25.3**	**63%**
P-2 East (Downstream from Kwage Canyon)													
Channel	c1	All	3114	2.0	6228	0.9	1.23	0.38	2.6	15%	100%	2.6	15%
Channel	c1b	Lower	297	2.1	624	0.9	1.23	0.38	0.3	2%	100%	0.3	2%
Channel	c2	Lower	5798	1.8	10436	0.9	1.23	0.38	4.4	26%	50%	2.2	13%
Channel	c3	Lower	743	0.5	372	0.9	1.23	0.38	0.2	1%	0%	0.0	0%
Subtotal			**9952**		**17660**				**7.4**	**43%**		**5.1**	**30%**
Overbank	c1b	Upper	297	0.13	39	0.9	1.04	2.42	0.1	1%	100%	0.1	1%
Overbank	c2	Upper	5798	0.5	2899	0.9	1.04	2.42	6.6	38%	50%	3.3	19%
Overbank	c3	Upper	743	0.25	186	0.93	1.04	5.31	1.0	6%	0%	0.0	0%
Overbank	f1	All	7613	0.13	990	0.85	1.04	2.42	2.1	12%	0%	0.0	0%
Subtotal					**4113**				**9.7**	**57%**		**3.4**	**20%**
Total					**21773**				**17.2**	**100%**		**8.4**	**49%**

3.3.4 Reach P-3

3.3.4.1 Plutonium Concentrations

Almost all samples from the c1, c2, c3, c4, and f1 units in reach P-3 contain plutonium-239,240 above background values (Table 3.3-7). The only exceptions are one sample collected at depth from the c4 unit in P-3 East (2.74 to 2.9 m deep at well PAO-1, sample location PU-0123) and two subsurface samples from the f1 unit in P-3 East (sample location PU-0169) that are below the background value and appear to record pre-1943 sediment deposits. In addition, analyses at or very near background values were obtained from f2 units in both P-3 West and P-3 East (sample locations PU-0143 and PU-0152). The plutonium concentrations in correlative units in P-3 West and P-3 East are generally very similar (Table 3.3-7), indicating similar sediment ages and little dilution between the subreaches; thus, samples from these two subreaches are combined for purposes of calculating summary statistics in this report.

Plutonium-239,240 concentrations within reach P-3 are highest in an overbank sediment sample from the top of the c4 unit in P-3 West, 45 pCi/g at sample location PU-0141 (Figure 2.3-13), although the next highest analysis is only 12 pCi/g, from a subsurface overbank sediment sample at an adjacent c3 sample site (sample location PU-0142). All analyses exceeding 5.6 pCi/g in P-3 were obtained from relatively fine-grained overbank sediments from the c3 and c4 units in both subreaches, and all the overbank sediment samples from these units are combined, yielding an average of 8.7 pCi/g and a median of 5.8 pCi/g (Table 3.3-8).

Plutonium concentrations are very similar between overbank sediment samples from the c2 and f1 units, consistent with their close spatial relation in P-3 and the similar ages of the bulk of the sediment in these units. One sediment sample from the top of the f2 unit in P-3 East (sample location PU-0152) also appears to record a thin sediment layer of the same age. The average and median plutonium concentrations from the c2 and f1 overbank sediments are relatively low as compared with overbank sediments in other reaches, only 1.5 and 1.2 pCi/g, respectively (Table 3.3-8).

Plutonium concentrations in the coarse-grained channel facies sediment in P-3 are generally less than in associated overbank sediment, with the highest analysis of 4.2 pCi/g obtained from the c3 unit. Averages and medians from the c3 channel facies samples, 3.1 and 3.5 pCi/g, are also much higher than in the other channel units (Table 3.3-8). Plutonium concentrations are similar in the c1 and c2 channel sediments in P-3, with averages and medians for the combined data set of 0.9 and 0.6 pCi/g. Concentrations in the older c4 channel sediments are lower, with averages and medians of 0.6 and 0.3 pCi/g. Much of the plutonium in the c4 channel sediments may represent plutonium that was associated with organic colloids and/or clay particles and was translocated vertically and horizontally into pre-1943 sediment, as indicated in Figure 3.3-8. This interpretation is in part based on evidence from reach P-4 (Section 3.3.5.1), where plutonium above the background value was consistently found in deep channel sediments that predate 1943.

Analyses from both channel facies and overbank facies sediment samples from deep sections in the c1 and c2 units in P-3 (1.35 to 2.15 m deep) have not revealed the presence of subsurface layers with plutonium concentrations that are elevated relative to near surface samples (Figures 3.3-9, 3.3-10, and 3.3-11). In contrast to the results from P-4 (Section 3.3.5), where there is significant vertical variability in plutonium concentration in thick channel units, there is thus no basis for vertically subdividing the thick P-3 units.

TABLE 3.3-7

REACH P-3 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a,b]	Soil Texture[b,c]	Notes
P-3 West (Hamilton Bend to treatment plant outfall channel)											
c1	PU-0146	0–4.5	0–12	Channel	1	04PU-97-0188	0.002 (U)[d]	0.909	(cs)	(s)	
c1	PU-0157	0–19.5	0–50	Channel	2	04PU-97-0244	0.031	0.354	cs	s	Limited-suite sample
		0–19.5	0–50	Channel	2	04PU-97-0245	0.0135 (U)	0.337	NA[e]	NA	QA duplicate
c1	PU-0173	31–38	80–95	Channel	3	04PU-98-0018	0.009 (U)	0.541	cs	gls	
		43–52	110–130	Channel	3	04PU-98-0017	-0.004 (U)	0.839	cs	s	
		72–80	185–205	Channel	3	04PU-98-0016	-0.002 (U)	0.469	cs	sl	
c2	PU-0145	4.5–11.5	11–29	Overbank	1	04PU-97-0184	-0.003 (U)	0.547	(vfs)	(sl)	
		16–28.5	41–73	Overbank	1	04PU-97-0185	-0.005 (U)	1.29	(vfs)	(sl)	
		28.5–40.5	73–103	Overbank	1	04PU-97-0186	0.007 (U)	2.28	(fs)	(sl)	
		40.5–53	103–135	Channel	1	04PU-97-0187	0.006 (U)	1.75	(cs)	(gs)	
c2	PU-0144	0–14	0–35	Channel	1	04PU-97-0181	0.001 (U)	0.538	(cs)	(gs)	
		0–14	0–35	Channel	2	04PU-97-0246	NA	NA	NA	NA	Layer resampled for limited suite
		14–19.5	35–50	Overbank	1	04PU-97-0182	0.007 (U)	0.468	(fs)	(sl)	
		14–19.5	35–50	Overbank	2	04PU-97-0247	NA	NA	NA	NA	Layer resampled for limited suite
		19.5–31.5	50–80	Channel	1	04PU-97-0183	0.011 (U)	2.35	cs	s	
c2	PU-0167	3–9	8–23	Channel	2	04PU-97-0257	0.026 (U)	0.435	cs	gs	
c3	PU-0142	0–3.5	0–9	Overbank	1	04PU-97-0177	0.012 (U)	3.51	vfs	sl	
		0–3.5	0–9	Overbank	2	04PU-97-0251	NA	NA	NA	NA	Layer resampled for limited suite

a. cs = coarse sand, fs = fine sand, vfs = very fine sand

b. No particle size data are available for 11 P-3 samples that were lost during shipping. Particle size characteristics for these samples are estimated from field notes and are shown in ( ).

c. sl = sandy loam, s = sand, g = ≥20% gravel

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

e. NA = not analyzed

TABLE 3.3-7 (continued)

REACH P-3 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a,b]	Soil Texture[b,c]	Notes
P-3 West (Hamilton Bend to treatment plant outfall channel)											
c3	PU-0142	3.5–12	9–30	Overbank	1	04PU-97-0178	0.071	11.7	fs	sl	
		3.5–12	9–30	Overbank	2	04PU-97-0248	NA[d]	NA	NA	NA	Layer resampled for limited suite
		3.5–12	9–30	Overbank	2	04PU-97-0249	NA	NA	NA	NA	QA duplicate
		19.5–35	49–89	Channel	1	04PU-97-0179	-0.001 (U)[e]	2.49	vcs	gs	
		19.5–35	49–89	Channel	2	04PU-97-0267	NA	NA	NA	NA	Layer resampled for limited suite
c3	PU-0166	0–6.5	0–17	Overbank	2	04PU-97-0252	0.0074 (U)	2.62	fs	sl	
		6.5–13	17–33	Channel	2	04PU-97-0253	0.0209 (U)	1.54	cs	gls	
		13–19.5	33–49	Overbank	2	04PU-97-0254	0.022 (U)	1.88	csi	l	
		19.5–23	49–58	Overbank	2	04PU-97-0255	0.073	8.31	vfs	sl	
		23–27.5	58–70	Channel	2	04PU-97-0256	0.019 (U)	3.85	cs	gs	
c4	PU-0141	1–4.5	2–11	Overbank	1	04PU-97-0176	0.136	44.9	fs	sl	
		1–4.5	2–11	Overbank	2	04PU-97-0250	NA	NA	NA	NA	Layer resampled for limited suite
		5–10	13–25	Overbank	2	04PU-97-0258	0.0179 (U)	5.87	vfs	sl	
		14–25	36–63	Channel	2	04PU-97-0259	0.0106 (U)	0.224	cs	s	
f1 (+c2)	PU-0148	0–12	0–30	Overbank	1	04PU-97-0193	0.005 (U)	0.897	(ms)	(sl)	
		12–20	30–51	Overbank	1	04PU-97-0194	0.007 (U)	1.08	(vfs)	(sl)	
		20–25.5	51–65	Overbank	1	04PU-97-0195	0.008 (U)	1.12	vfs	sl	
		25.5–33.5	65–85	Overbank	1	04PU-97-0196	0.005 (U)	3.33	(vfs)	(sl)	

a. vcs = very coarse sand, cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. No particle size data are available for 11 P-3 samples that were lost during shipping. Particle size characteristics for these samples are estimated from field notes and are shown in ( ).

c. l = loam, ls = loamy sand, sl = sandy loam, s = sand, g = ≥20% gravel

d. NA = not analyzed

e. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

TABLE 3.3-7 (continued)

REACH P-3 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a,b]	Soil Texture[b,c]	Notes
P-3 West (Hamilton Bend to treatment plant outfall channel)											
f1	PU-0147	0–5.5	0–14	Overbank	1	04PU-97-0189	0.016 (U)[d]	5.58	(vfs)	(sl)	
		5.5–12	14–30	Overbank	1	04PU-97-0190	0 (U)	1.54	csi	sil	
		12–17	30–43	Overbank	1	04PU-97-0191	0.006 (U)	0.562	vfs	sl	
		12–17	30–43	Overbank	1	04PU-97-0192	-0.002 (U)	0.525	NA[e]	NA	QA duplicate
f1	PU-0168	0–2	0–5	Overbank	2	04PU-97-0266	0.027 (U)	3.03	csi	sl	
f2	PU-0143	0–5.5	0–14	Channel	1	04PU-97-0180	-0.001 (U)	0.072	cs	s	Background?
P-3 East (Downstream from treatment plant road)											
c2	PU-0154	0–10	0–25	Overbank	1	04PU-97-0205	0.02	0.758	ms	gls	
		10–17.5	25–44	Overbank	1	04PU-97-0206	-0.001 (U)	1.18	csi	l	
c2	PU-0155	0–5	0–13	Overbank	1	04PU-97-0207	0.005 (U)	1.46	vfs	sl	
		5–12.5	13–32	Overbank	1	04PU-97-0208	-0.001 (U)	1.93	csi	sil	
c2	PU-0172	48–55	120–140	Channel	3	04PU-98-0008	0.002 (U)	0.677	cs	gs	
		55–72	140–180	Channel	3	04PU-98-0009	0.009 (U)	0.453	cs	s	
Tpf	PU-0172	84–88	215–225		3	04PU-98-0010	0.006 (U)	0.015	NA	NA	Puye Formation
c3	PU-0149	0–3	0–8	Overbank	1	04PU-97-0197	0.036	7.93	vfs	sl	
		9.5–21.5	24–55	Channel	1	04PU-97-0198	-0.001 (U)	4.23	cs	gs	
c3	PU-0150	0–3	0–8	Overbank	1	04PU-97-0199	0.024	5.84	vfs	sl	
		7–15	18–38	Channel	1	04PU-97-0200	0 (U)	3.45	cs	gs	
c4	PU-0123	39.5–48	100–122	Channel	0	04LA-97-0230	0.0063 (U)	1.48	cs	gs	Well PAO-1 core
		48–72	122–183	Channel	0	04LA-97-0231	0.0048 (U)	1.261	cs	gs	Well PAO-1 core
		96–108	244–274	Channel	0	04LA-97-0232	0.001 (U)	0.756	cs	gls	Well PAO-1 core

a. cs = coarse sand, ms = medium sand, vfs = very fine sand, csi = coarse silt

b. No particle size data are available for 11 P-3 samples that were lost during shipping. Particle size characteristics for these samples are estimated from field notes and are shown in ( ).

c. l = loam, sl = sandy loam, ls = loamy sand, s = sand, sil = silt loam, g = ≥20% gravel

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

e. NA = not analyzed

TABLE 3.3-7 (continued)

REACH P-3 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Depth (in.)	Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-3 East (Downstream from treatment plant road)											
c4	PU-0123	108–114	274–290	Overbank	0	04LA-97-0234	0.0085 (U)[c]	0.0134	vfs	gsl	Well PAO-1 core, background?
		120–132	305–335	Channel	0	04LA-97-0235	0.0033 (U)	0.326	cs	gls	Well PAO-1 core
		132–144	335–365	Channel	3	04PU-98-0030	0.002 (U)	0.209	cs	gls	Well PAO-1 core
		150–162	380–410	Channel	3	04PU-98-0031	-0.003 (U)	0.108	ms	gls	Well PAO-1 core
c4	PU-0170	0–4.5	0–11	Overbank	2	04PU-97-0264	-0.0006 (U)	2.15	ms	ls	
		4.5–6.5	11–17	Overbank	2	04PU-97-0265	0.0088 (U)	0.453	vfs	sl	
		14–35.5	36–90	Channel	2	04PU-97-0268	0.0052 (U)	0.073	cs	s	
f1	PU-0151	0–3.5	0–9	Overbank	1	04PU-97-0201	0.012 (U)	2.81	csi	sil	
f1	PU-0153	0–2.5	0–7	Overbank	1	04PU-97-0203	-0.001 (U)	1.67	vfs	sl	
		2.5–5	7–13	Overbank	1	04PU-97-0204	0.075	0.218	vfs	sl	
f1	PU-0169	0–5	0–13	Overbank	2	04PU-97-0261	0 (U)	0.126	vfs	sl	
		5–9.5	13–24	Overbank	2	04PU-97-0262	0.0034 (U)	0.0253	vfs	sl	Background?
		9.5–15	24–38	Overbank	2	04PU-97-0263	-0.0052 (U)	0.045	vfs	sl	Background?
f2? (f1?)	PU-0152	0–2	0–5	Overbank	1	04PU-97-0202	0.007 (U)	0.457	fs	sl	
		4.5–15.5	11–40	Channel	2	04PU-97-0260	-0.0043 (U)	0.0055	cs	s	Background

a. cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand

b. sl = sandy loam, ls = loamy sand, s = sand, sil = silt loam, g = ≥20% gravel

c. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

TABLE 3.3-8

SUMMARY OF BINNED PLUTONIUM ANALYSES IN REACH P-3

Geomorphic Unit and Sediment Facies	Summary Statistic	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Median Particle Size (mm)	Soil Texture[b]	Pu-239/238 ratio
c1 and c2 channel	average	0.009	0.885	cs	0.774	gs	95
	std. dev.	0.011	0.654				
	maximum	0.031	2.350				
	minimum	-0.004	0.354				
	median	0.008	0.609				
	n	10	10				
c3 channel	average	0.008	3.112	cs	0.800	gs	411
	std. dev.	0.011	1.092				
	maximum	0.021	4.230				
	minimum	-0.001	1.540				
	median	0.000	3.450				
	n	5	5				
c4 channel	average	0.004	0.555	cs	0.682	gls	147
	std. dev.	0.004	0.549				
	maximum	0.011	1.480				
	minimum	-0.003	0.073				
	median	0.004	0.275				
	n	8	8				
c2, f1, and f2 overbank	average	0.0093	1.5397	vfs	0.069	l	165
	std. dev.	0.0169	1.2980				
	maximum	0.0750	5.5800				
	minimum	-0.0050	0.1260				
	median	0.0060	1.1800				
	n	21	21				
c3 and c4 overbank	average	0.037	8.651	vfs	0.114	sl	234
	std. dev.	0.041	12.481				
	maximum	0.136	44.900				
	minimum	-0.001	0.453				
	median	0.022	5.840				
	n	11	11				
background?[c]	average	0.001	0.029	ms	0.337	ls	24
	std. dev.	0.006	0.025				
	maximum	0.009	0.072				
	minimum	-0.005	0.006				
	median	0.001	0.020				
	n	6	6				

a. cs = coarse sand, ms = medium sand, vfs = very fine sand

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

c. Samples inferred to represent background values have ≤0.72 pCi/g Pu-239,240 and are from c4, f1, f2, and Puye Formation

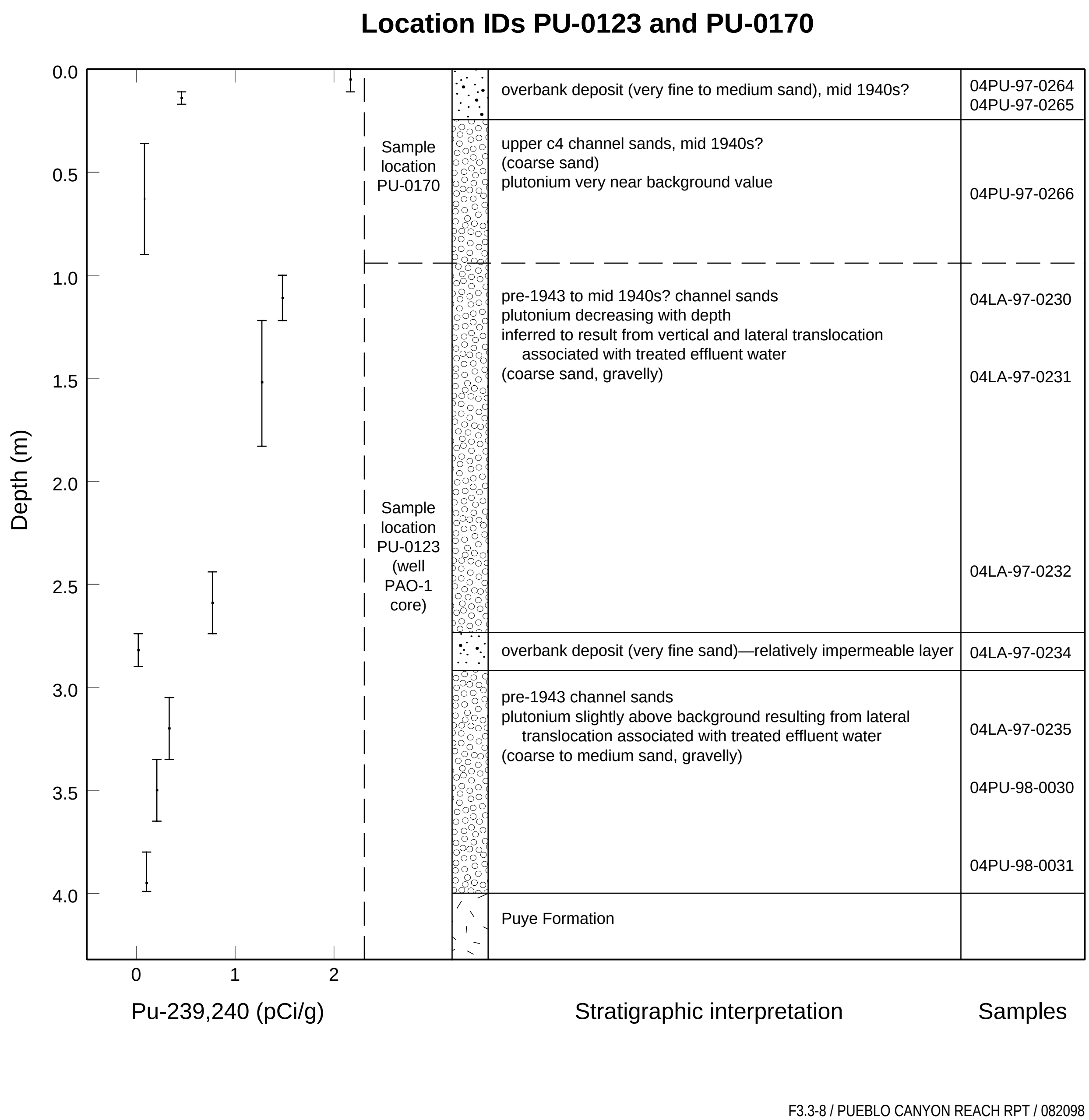


Figure 3.3-8. Depth variations in plutonium-239,240 concentration at sample sites in the c4 unit in reach P-3 East.

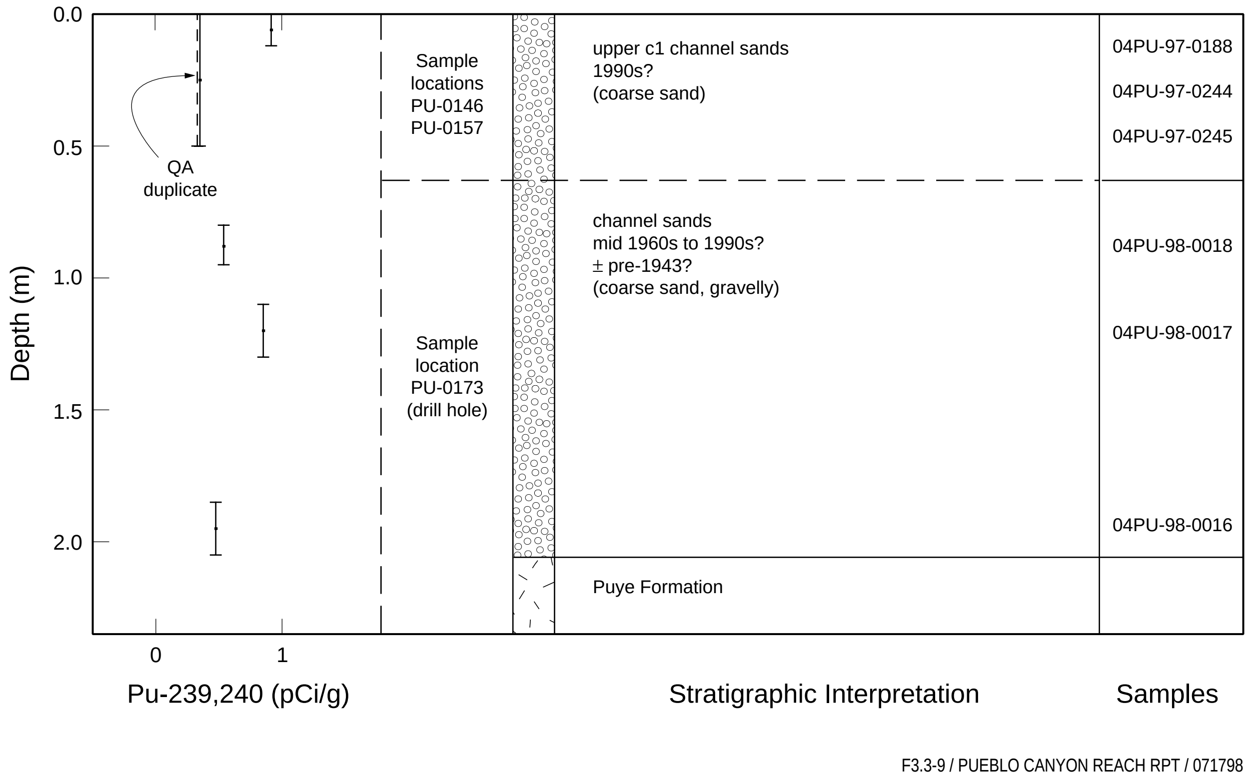


Figure 3.3-9. Depth variations in plutonium-239,240 concentration at sample sites in the c1 unit in reach P-3 West.

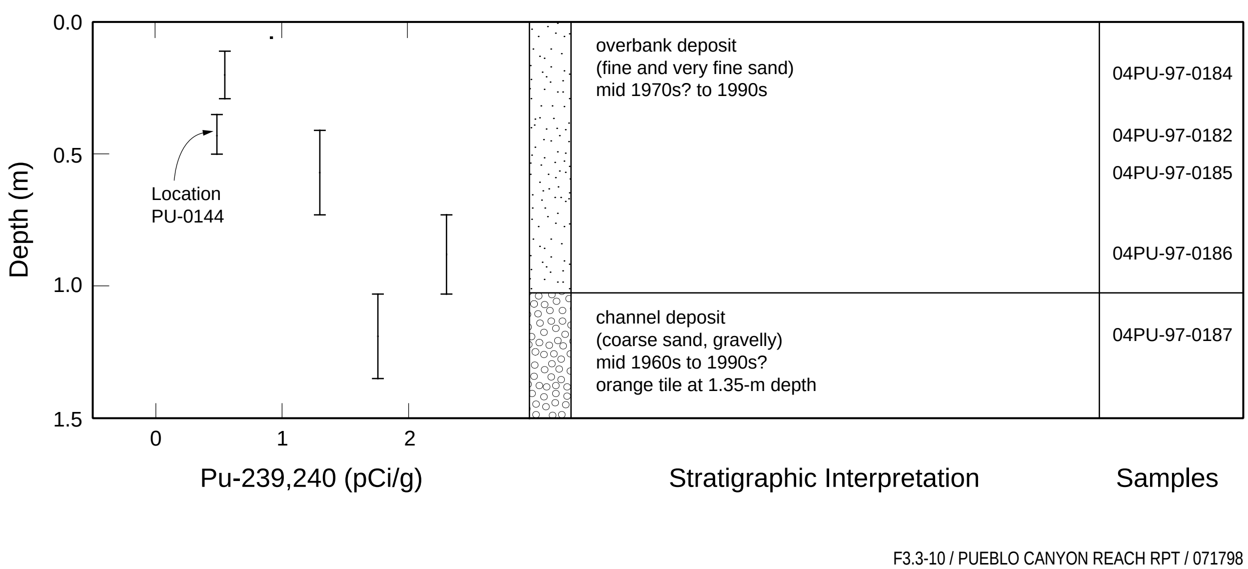
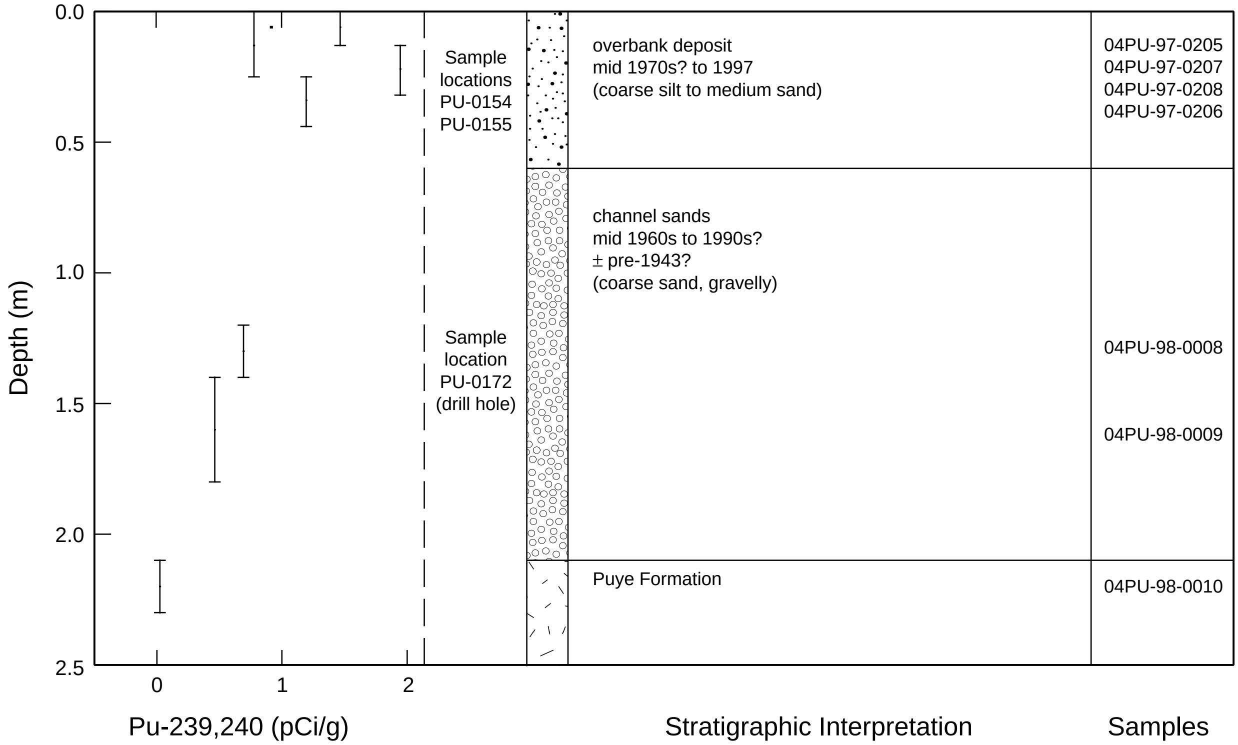


Figure 3.3-10. Depth variations in plutonium-239,240 concentration at sample sites in the c2 unit in reach P-3 West.



F3.3-11 / PUEBLO CANYON REACH RPT / 071798

Figure 3.3-11. Depth variations in plutonium-239,240 concentration at sample sites in the c2 unit in reach P-3 East.

One sample of Puye Formation sediment from a depth of 2.15 to 2.25 m immediately below the alluvium at a drill hole through the c2 unit in P-3 East (sample location PU-0172, Figure 3.3-11) was submitted for plutonium analysis to determine if significant amounts of plutonium had been transported vertically from the alluvium into the substrate. Plutonium was reported above the detection limit but below the background value (0.015 pCi/g plutonium-239,240, sample 04PU-98-0010), which indicates that little transport of plutonium into the substrate has occurred here.

3.3.4.2 Age and Particle Size Relations

Temporal trends in plutonium concentration are poorly defined in reach P-3, and it appears that channel facies sediment from the period when plutonium concentrations were highest (represented by the c4b and c5 units in P-4 West, discussed in Section 3.3.5) are not present in P-3 or are present only in small volumes that cannot be distinguished in the field and were not sampled in this investigation. The highest plutonium concentrations in channel facies sediment in P-3 were obtained from the c3 unit, in areas where the stream channel was apparently located in 1954 (Figures 2.3-15 and 2.3-16), but the relatively low plutonium concentrations as compared with samples in P-4 West suggest that these sediments are older than 1954 and are from the very early post-1942 period. No consistent trends with depth that could indicate temporal trends are apparent in samples from the c1 and c2 units in P-3 (Figures 3.3-9, 3.3-10, and 3.3-11). Tree-ring dating near c2 sample location PU-0167 in P-3 West (trees PUB-013, PUB-015, Table B1-1) indicate that the upper sand and gravel layer postdates 1987 and was probably deposited during the August 1991 floods, and much of the upper c1 and c2 deposits in P-3 may similarly date to 1991. Tree-ring dating in an adjacent c3 unit in P-3 East (trees PUB-012, PUB-014, Table B1-1) indicates that the overbank sediments at that location postdate 1965 and that the underlying channel deposits predate 1956.

Data from two environmental surveillance sampling stations provide additional data on potential variations in plutonium concentration with age in Pueblo Canyon: a station at Hamilton Bend Spring in P-3 West and station Pueblo 3, located immediately east of P-3 East (Figure 3.3-12). The data from Hamilton Bend Spring, extending back to 1978, average 0.5 pCi/g and are mostly less than 1 pCi/g. These data are generally similar to the plutonium data from channel facies sediment from the c1 and c2 units in P-3, although the data from this investigation average slightly higher, 0.9 pCi/g. The data from Pueblo 3, extending back to 1979, are very hard to interpret. Plutonium concentrations as high as 15.5 pCi/g have been reported from Pueblo 3, higher than from any other station downstream from Acid Canyon, but half of the analyses are below the background value of 0.068 pCi/g. This station is in a grassy area with a high water table downstream from the Bayo Canyon WWTP outfall, and the channel is unlike that at any other sampling station, lacking a coarse sandy bed at present (1997 and 1998). Thus, the nature of the samples collected here is unclear, and the data from Pueblo 3 are not considered useful for this investigation.

Relations between particle size characteristics and plutonium concentration are very poorly defined in P-3 relative to other reaches (Figure B3-3). These poor relationships may be due in part to the samples spanning a range in age and being affected by time-dependent variations in plutonium, combined with the relatively low concentrations of plutonium in this reach (with few samples exceeding 10 pCi/g). Mixing of variable amounts of sediment derived from Kwage Canyon that contain background levels of plutonium with sediment from upstream parts of Pueblo Canyon may also contribute to the poor relations between plutonium concentration of particle size in reach P-3.

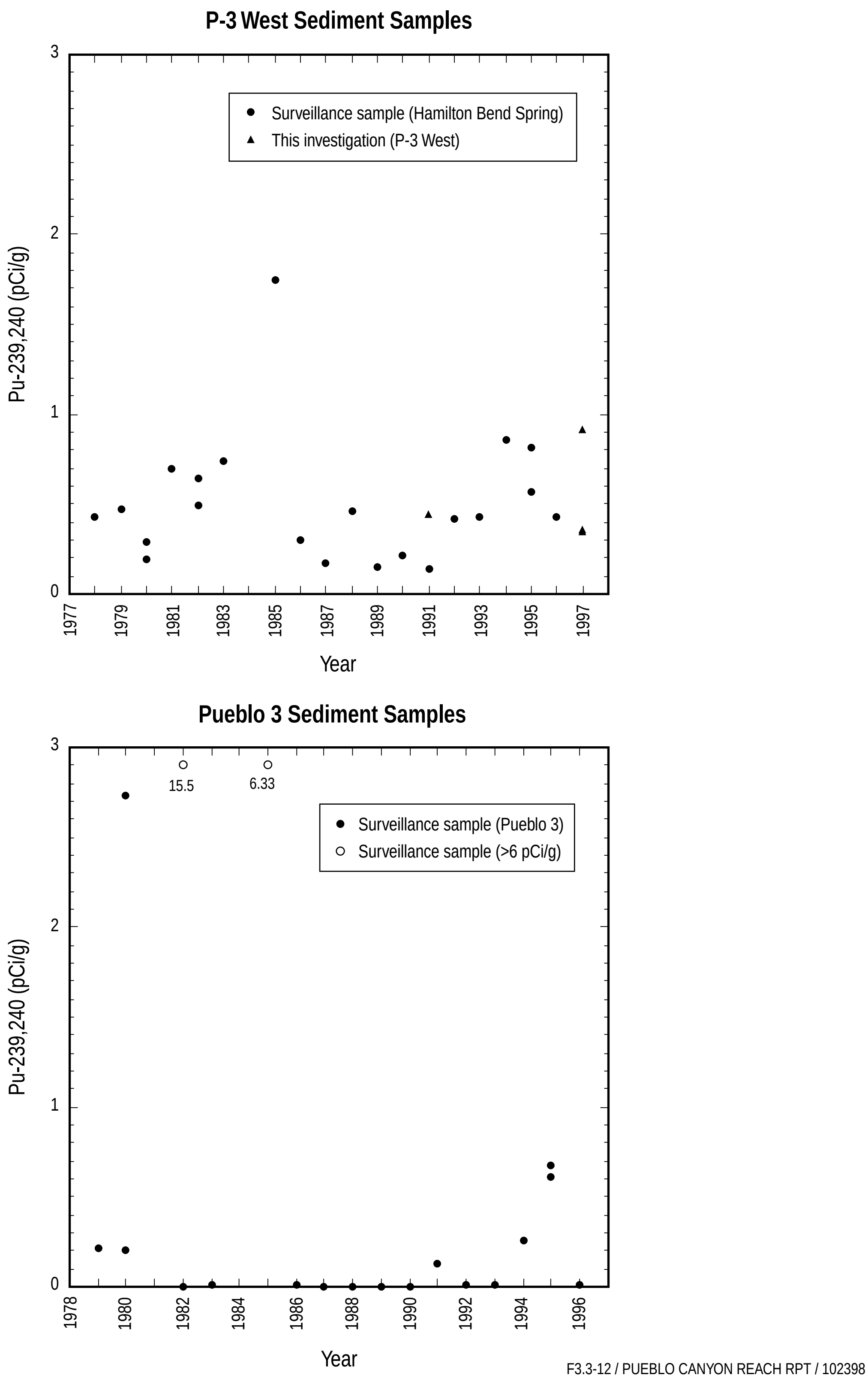


Figure 3.3-12. Relation of plutonium-239,240 concentration to age from active channel sediment samples collected in reach P-3 West and from the environmental surveillance station Pueblo 3 east of reach P-3 East.

3.3.4.3 Plutonium Inventory

Most of the estimated plutonium-239,240 inventory in reach P-3 is contained with channel facies sediment, 64% in P-3 West and 54% in P-3 East (Table 3.3-9), contrasting with upstream reaches where most of the plutonium is estimated to reside in overbank facies sediment. The most important geomorphic unit in P-3 West in terms of total estimated storage of plutonium is the c3 unit, containing an estimated 40% of the plutonium in that subreach. In P-3 East the most important unit is the c2 unit, with an estimated 61% of the total inventory. Total plutonium in P-3 West, approximately 43 mCi/km, is somewhat less than that in P-3 East, approximately 73 mCi/km, associated with the smaller volume of post-1943 sediment in the former. In both subreaches, most of the plutonium is stored in sites potentially subject to remobilization if a period of major channel incision occurred.

3.3.5 Reach P-4

3.3.5.1 Plutonium Concentrations

Almost all samples from the channel and floodplain units in reach P-4 contain plutonium-239,240 above background values (Table 3.3-10). Several samples from floodplain units contain plutonium within background ranges or slightly above background values but have low concentrations relative to other floodplain samples in P-4, suggesting that there have been only minor additions of plutonium-bearing sediment to these sampled layers. The plutonium concentrations within and between units in P-4 West and P-4 East are generally consistent with particle size variations and inferred age; thus, samples from these two subreaches are combined for purposes of calculating summary statistics in this report.

Plutonium-239,240 concentrations within reach P-4 are highest in a fine-grained overbank facies sample from within the c6 unit in P-4 West, 170.5 pCi/g at sample location PU-0093, which is higher than any other sample collected downstream of P-1 (Table 3.3-10; Figure 3.3-13). Resampling of this layer yielded a lower concentration of 62.8 pCi/g, which confirms relatively high plutonium concentrations within this layer but also indicates significant variability within specific sample layers (see also Appendix E). The sampled layer with the second highest plutonium in P-4 is located nearby within overbank facies sediment in the same c6 unit, with 38 and 18 pCi/g in two sampling events (sample location PU-0045), also providing an indication of the degree of local variability (Figure 3.3-13). The average plutonium concentration in overbank facies of the c6 unit and related c5 samples is 37.8 pCi/g, and the median is 11.3 pCi/g (Table 3.3-11).

Overbank facies sediment samples from other geomorphic units in P-4 have lower concentrations of plutonium, and most samples from c1, c3, c4, c5, and f1 units are considered to represent sediment of similar age and are grouped together. Overbank facies samples from these units have an average of 6.0 pCi/g plutonium 239,240, a median of 5.5 pCi/g, and a maximum of 18.7 pCi/g (Table 3.3-11). The widespread f1a unit in P-4 West has plutonium above background levels but low relative to other overbank samples because of the preponderance of sediment derived from tributary drainages from the south side of Pueblo Canyon, with a maximum of 0.6 pCi/g and an average of 0.4 pCi/g.

TABLE 3.3-9

ESTIMATED PLUTONIUM INVENTORY IN REACH P-3

Sediment Facies	Geomorphic Unit	Section	Area (m^2)	Estimated Average Thickness (m)	Estimated Volume (m^3)	Estimated Fraction <2 mm	Estimated Density (g/cm^3)	Estimated Average Pu-239,240 Concentration (pCi/g)	Estimated Pu-239,240 Inventory (mCi)	Percent of Total Subreach Inventory	Percent Potentially Susceptible to Remobilization	Estimated Inventory Most Susceptible to Remobilization (mCi)	Percent of Total Subreach Inventory Susceptible to Remobilization
P-3 West (Hamilton Bend to Treatment Plant outfall channel)													
Channel	c1	Lower	2888	2.0	5776	0.7	1.23	0.85	4.2	20%	100%	4.2	20%
Channel	c2	Lower	3471	1.9	6595	0.7	1.23	0.85	4.8	22%	100%	4.8	22%
Channel	c3	Lower	1908	1.0	1908	0.6	1.23	3.11	4.4	20%	30%	1.3	6%
Channel	c4	Lower	340	1.0	340	0.6	1.23	0.56	0.1	1%	50%	0.1	0%
Subtotal					**14619**				**13.6**	**63%**		**10.4**	**48%**
Overbank	c1	Upper	2888	0.04	116	0.87	1.04	1.54	0.2	1%	100%	0.2	1%
Overbank	c2	Upper	3471	0.29	1007	0.87	1.04	1.54	1.4	7%	100%	1.4	7%
Overbank	c3	Upper	1908	0.28	534	0.91	1.04	8.65	4.4	20%	30%	1.3	6%
Overbank	c4	Upper	340	0.22	75	0.83	1.04	8.65	0.6	3%	50%	0.3	1%
Overbank	f1	All	3855	0.20	771	0.93	1.04	1.54	1.1	5%	0%	0.0	0%
Overbank	f2	All	4310	0.05	216	0.94	1.04	1.54	0.3	2%	0%	0.0	0%
Subtotal					**2718**				**8.0**	**37%**		**3.2**	**15%**
Total					**17337**				**21.5**	**100%**		**13.6**	**63%**
P-3 East (Downstream from Treatment Plant road)													
Channel	c1	All	1818	1.5	2727	0.7	1.23	0.85	2.0	5%	100%	2.0	5%
Channel	c2	Lower	13215	1.5	19823	0.7	1.23	0.85	14.5	38%	100%	14.5	38%
Channel	c3	Lower	458	1.5	687	0.6	1.23	3.11	1.6	4%	0%	0.0	0%
Channel	c4	Lower	1904	3.0	5712	0.6	1.23	0.56	2.4	6%	0%	0.0	0%
Subtotal					**28949**				**20.4**	**53%**		**16.5**	**43%**
Overbank	c2	Upper	13215	0.49	6475	0.87	1.04	1.54	9.0	23%	100%	9.0	23%
Overbank	c3	Upper	458	0.08	37	0.91	1.04	8.65	0.3	1%	0%	0.0	0%
Overbank	c4	Upper	1904	0.50	952	0.83	1.04	8.65	7.1	18%	0%	0.0	0%
Overbank	f1	All	10514	0.09	946	0.93	1.04	1.54	1.4	4%	0%	0.0	0%
Overbank	f2	All	3348	0.05	167	0.94	1.04	1.54	0.3	1%	0%	0.0	0%
Subtotal					**8578**				**18.1**	**47%**		**9.0**	**23%**
Total					**37527**				**38.5**	**100%**		**25.5**	**66%**

TABLE 3.3-10

REACH P-4 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-4 West											
c1	PU-0089	0–2	0–5	Channel	3	04PU-97-0021	0.03 (U)[c]	0.27	cs	gs	
c4a	PU-0048	0–4	0–10	Channel	2	04PU-96-0236	0.011 (U)	2.4	cs	s	
c4a	PU-0055	0–3	0–8	Channel	2	04PU-96-0237	0.027 (J)[d]	1.6	cs	s	
c4a	PU-0083	0–12	0–30	Channel	3	04PU-97-0007	0.02 (U)	1.2	cs	s	
		20–43	50–110	Channel	3	04PU-97-0008	0.02 (U)	1.26	cs	s	
		51–67	130–170	Channel	3	04PU-97-0009	0 (U)	1.58	cs	gs	c6 age sediment?
		71–82.5	180–210	Channel	4	04PU-97-0121	0.06 (U)	1.05	cs	s	c6 age sediment?
c4b	PU-0047	0–4.5	0–11	Overbank	2	04PU-96-0234	0.048 (J)	5.9	fs	sl	
		5–14	13–36	Channel	2	04PU-96-0235	0.083 (J)	8.5	cs	s	
c4b	PU-0049	0–7	0–18	Overbank	2	04PU-96-0238	0.045 (J)	7.4	fs	ls	
		7–15	18–38	Channel	2	04PU-96-0239	0.079 (J)	5.5	cs	s	
c4b	PU-0087	0–3	0–8	Overbank	3	04PU-97-0016	0.02 (U)	7.22	csi	l	
		6–12	15–30	Channel	3	04PU-97-0017	0 (U)	3.18	cs	s	
c4b	PU-0088	16–31	40–80	Channel	3	04PU-97-0018	0 (U)	2.94	cs	gs	
		35–51	90–130	Channel	3	04PU-97-0019	0.02 (U)	2.45	vcs	gs	c6 age sediment?
		55–71	140–180	Channel	3	04PU-97-0020	0.07 (U)	3.15	vcs	gs	c6 age sediment?
		75–90.5	190–230	Channel	4	04PU-97-0122	0 (U)	2.98	cs	s	c6 age sediment?
c5	PU-0037	0–1.5	0–4	Overbank	1	04PU-96-0030	0.038	4.233	vfs	sl	Full-suite sample
c5	PU-0039	0–3	0–8	Channel	1	04PU-96-0032	0.021	4.746	cs	s	Full-suite sample
c5	PU-0046	0–3	0–8	Channel	2	04PU-96-0233	0.064 (J)	16	cs	s	
c5	PU-0090	0–3	0–8	Overbank	3	04PU-97-0022	0.08 (U)	3.71	vfs	gl	
		4–13	10–33	Channel	3	04PU-97-0023	0.17 (J)	4.56	cs	s	

a. vcs = very coarse sand, cs = coarse sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, g = ≥20% gravel

c. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit.

d. J = The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.

TABLE 3.3-10 (continued)

REACH P-4 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-4 West											
c5	PU-0091	10–15	25–38	Overbank	3	04PU-97-0024	0.08 (J)[c]	8.86	vfs	gsl	Equivalent to c6 overbank?
		16–23	41–58	Channel?	3	04PU-97-0025	0.05 (U)[d]	6.82	ms	gsl	
		23–27	58–69	Channel?	3	04PU-97-0026	0.07 (U)	12.82	ms	s	
		34–44	86–112	Channel	3	04PU-97-0027	0.02 (U)	0.23	cs	s	c6 age sediment?
		48–57	122–145	Overbank	3	04PU-97-0028	0.1 (U)	3.41	fs	gsl	c6 age overbank sediment?
		48–57	122–145	Overbank	3	04PU-97-0029	0 (U)	3.92	NA[e]	NA	QA duplicate
		58–70	147–178	Channel	3	04PU-97-0030	0.03 (U)	2.56	cs	s	c6 age sediment?
		73–88.5	185–225	Channel	4	04PU-97-0124	0.1 (U)	0.66	cs	gs	c6 age sediment?
c6	PU-0040	0–3	0–8	Overbank	1	04PU-96-0033	0.075	11.265	vfs	l	Full-suite sample
c6	PU-0045	0–8	0–20	Overbank	2	04PU-96-0231	0.13	38	fs	sl	
		0–8	0–20	Overbank	3	04PU-97-0005	0.1 (U)	18.47	fs	sl	Layer resampled for limited suite
		10–18	25–45	Channel	2	04PU-96-0232	0.017 (U)	2.5	cs	s	
c6	PU-0051	16–30	40–75	Channel	2	04PU-96-0240	0.022 (U)	0.23	cs	s	
c6	PU-0085	0–6	0–15	Overbank	3	04PU-97-0011	0.08 (U)	10.58	fs	sl	
		10–16	25–40	Channel	3	04PU-97-0012	0.08 (U)	0.28	cs	s	
c6	PU-0092	0–3	0–8	Overbank	3	04PU-97-0031	0.1 (U)	8.52	fs	sl	
		6–16	15–41	Channel	3	04PU-97-0032	0.02 (U)	0.25	cs	s	
c6	PU-0093	0–6	0–15	Overbank	5	04PU-97-0270	0.084	17.1	vfs	sl	
		6–10	15–25	Overbank	3	04PU-97-0033	0.62	170.5	csi	l	

a. cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, s = sand, g = ≥20% gravel

c. J = The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit

e. NA = not analyzed

TABLE 3.3-10 (continued)

REACH P-4 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-4 West											
c6	PU-0093	6–10	15–25	Overbank	5	04PU-97-0269	0.218	62.8	NA[c]	NA	Layer resampled for limited suite
		10–15.5	25–40	Channel	5	04PU-97-0271	-0.0102 (U)[d]	0.516	ms	ls	
		15.5–22	40–56	Channel	5	04PU-97-0272	0.02 (U)	0.479	cs	s	
		22–29.5	56–75	Channel	5	04PU-97-0273	0.0035 (U)	0.051	cs	s	
f1	PU-0038	0–2.5	0–6	Overbank	1	04PU-96-0031	0.01	3.416	fs	ls	Full-suite sample
f1	PU-0084	0–5	0–13	Overbank	3	04PU-97-0010	0.08 (U)	4.92	vfs	sl	
f1	PU-0086	0–3	0–8	Overbank	3	04PU-97-0013	0 (U)	5.45	fs	sl	
		0–3	0–8	Overbank	3	04PU-97-0014	0.08 (U)	6.37	NA	NA	QA duplicate
		7–11	18–28	Overbank	3	04PU-97-0015	0.12 (U)	5.48	vfs	sl	
f1a	PU-0082	0–6	0–15	Overbank	3	04PU-97-0006	0 (U)	0.5	csi	l	
f1a	PU-0094	0–4	0–10	Overbank	3	04PU-97-0034	0.1 (U)	0.55	csi	l	
		8–11	20–28	Overbank	3	04PU-97-0035	0 (U)	0.1 (U)	csi	sil	
P-4 East											
c1	PU-0095	0–4	0–10	Overbank	3	04PU-97-0036	0.08 (U)	0.59	csi	sil	
c1	PU-0096	6–14	15–36	Channel	3	04PU-97-0037	0.03 (U)	3.18	cs	gs	
c1b	PU-0034	0–2.5	0–6	Channel	1	04PU-96-0027	0.003 (U)	0.539	cs	s	Full-suite sample
c1b	PU-0052	0–1.5	0–4	Channel	2	04PU-96-0227	0.054 (U)	2.1	cs	s	
c3	PU-0032	28–35	70–90	Overbank	1	04PU-96-0025	0.003 (U)	1.494	fs	ls	Full-suite sample
c3	PU-0033	10–14	25–35	Channel	1	04PU-96-0026	0.005 (U)	1.056	cs	s	Full-suite sample; black sand
		20–37	50–95	Channel	3	04PU-97-0043	0.1 (U)	0.93	cs	gs	

a. cs = coarse sand, ms = medium sand, fs = fine sand, vfs = very fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, sil = silt loam, g = ≥20% gravel

c. NA = not analyzed

d. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit

TABLE 3.3-10 (continued)

REACH P-4 PLUTONIUM ANALYSES

Geomorphic Unit	Location ID	Sample Depth (in.)	Sample Depth (cm)	Sediment Facies	Sampling Event	Sample ID	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size Class[a]	Soil Texture[b]	Notes
P-4 East											
c3	PU-0033	43–53	110–135	Channel	3	04PU-97-0044	0.13 (U)[c]	4.42	cs	gs	c4b+c5 age sediment?
		43–53	110–135	Channel	3	04PU-97-0045	0.06 (U)	6.58	NA[d]	NA	QA duplicate
		59–79	150–200	Channel	3	04PU-97-0046	0.02 (U)	1.29	cs	s	c6 age sediment?
		71–73	180–185	Channel	4	04PU-97-0120	0.02 (U)	0.6	cs	gs	Resampled part of layer
c3	PU-0035	0–2	0–5	Channel	1	04PU-96-0028	0.002 (U)	0.759	cs	s	Full-suite sample
c3	PU-0053	0–2	0–5	Channel	2	04PU-96-0228	0.006 (U)	2.3	cs	s	
c3	PU-0099	5–10	13–25	Overbank	3	04PU-97-0042	0.08 (U)	3.53	csi	gl	
c3	PU-0103	0–2	0–5	Channel	3	04PU-97-0050	0 (U)	0.72	cs	s	
f1	PU-0036	0–2	0–5	Overbank	1	04PU-96-0029	0.038	6.214	csi	sl	Full-suite sample
f1	PU-0041	0–2.5	0–6	Overbank	2	04PU-96-0223	0.009 (U)	0.25	fs	sl	Near background?
		13–17	33–43	Overbank	2	04PU-96-0224	0.014 (J)[e]	0.038 (J)	ms	ls	Background?
f1	PU-0097	12–16	30–40	Overbank	3	04PU-97-0038	0.15 (U)	9.24	csi	sil	
		16–18	40–45	Overbank	3	04PU-97-0039	0.22 (J)	18.65	csi	sil	
f1	PU-0098	0–2	0–5	Overbank	3	04PU-97-0040	0.27 (J)	8.53	csi	sil	
		10–17	20–35	Channel	3	04PU-97-0041	0.12 (U)	0.12	cs	s	c3 age sediment?
f1	PU-0100	0–3	0–8	Overbank	3	04PU-97-0047	0.03 (U)	4.73	csi	sil	
f1	PU-0101	4–15	10–38	Overbank	3	04PU-97-0048	0.04 (U)	7.94	csi	l	
f1	PU-0102	0–3	0–8	Overbank	3	04PU-97-0049	0.08 (U)	5.22	csi	sil	
f2	PU-0042	0–3	0–8	Overbank	2	04PU-96-0225	0.022 (J)	0.15	fs	sl	Near background?
		11–16	28–40	Channel	2	04PU-96-0226	0.002 (U)	0.024 (J)	cs	s	Background?
f2	PU-0044	0–2	0–5	Overbank	2	04PU-96-0230	0.035 (J)	0.069 (J)	ms	ls	Background?
f2	PU-0054	0–3	0–8	Overbank	2	04PU-96-0229	0.019 (U)	0.16	fs	sl	Near background?

a. cs = coarse sand, ms = medium sand, fs = fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand, sil = silt loam, g = ≥20% gravel

c. U = The analyte was analyzed for but not detected. Reported value is the sample-specific estimated quantitation limit or detection limit

d. NA = not analyzed

e. J = The analyte was positively identified, and the associated numerical value is estimated to be more uncertain than would normally be expected for that analysis.

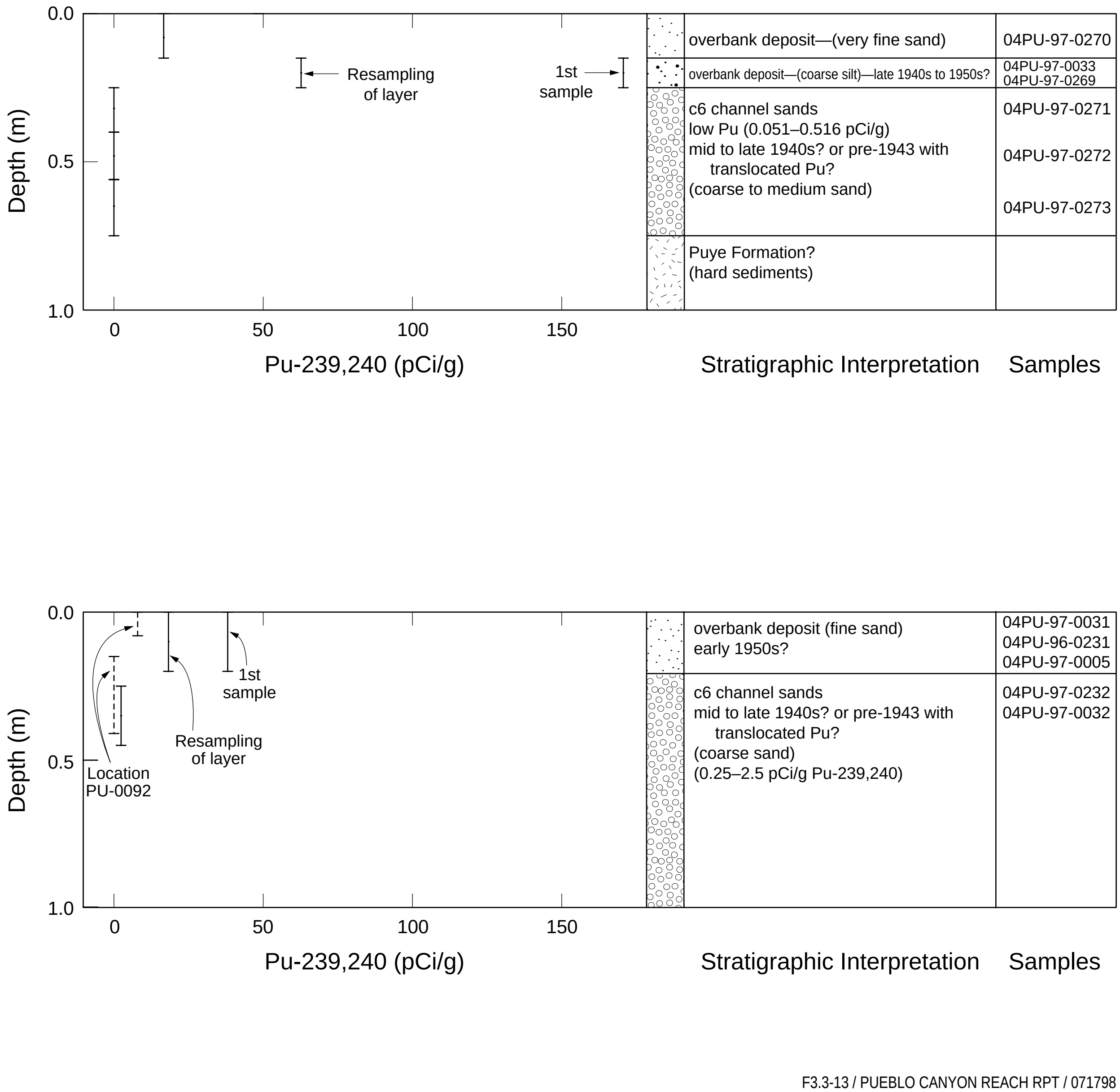


Figure 3.3-13. Depth variations in plutonium-239,240 concentration at sample sites in the c6 unit in reach P-4 West.

TABLE 3.3-11

SUMMARY OF BINNED PLUTONIUM ANALYSES IN REACH P-4

Geomorphic Unit and Sediment Facies	Summary Statistic	Pu-238 (pCi/g)	Pu-239,240 (pCi/g)	Median Particle Size (mm)	Median Particle Size Class[a]	Soil Texture[b]	Pu-239/238 ratio
young channel deposits (c1, c1b, c3, c4a, and f1)	average	0.031	1.317	0.637	cs	s	43
	std. dev.	0.037	0.892				
	maximum	0.120	3.180				
	minimum	0.000	0.120				
	median	0.020	1.128				
	n	14	14				
older channel deposits (c4b, c5, and some c3)	average	0.067	6.949	0.619	cs	s	104
	std. dev.	0.054	4.322				
	maximum	0.170	16.000				
	minimum	0.000	2.940				
	median	0.067	5.123				
	n	10	10				
oldest channel deposits (c6 and some c3, c4a, c5)	average	0.030	1.266	0.795	cs	s	43
	std. dev.	0.031	1.108				
	maximum	0.100	3.150				
	minimum	-0.010	0.051				
	median	0.020	0.855				
	n	16	16				
young overbank deposits (c1, c1b, c3, c4b, c5, and f1)	average	0.075	5.993	0.062	csi	l	80
	std. dev.	0.072	3.792				
	maximum	0.270	18.650				
	minimum	0.000	0.590				
	median	0.048	5.450				
	n	19	19				
old overbank deposits (c6 and some c5)	average	0.167	37.832	0.106	vfs	sl	227
	std. dev.	0.201	59.411				
	maximum	0.620	170.500				
	minimum	0.075	8.520				
	median	0.084	11.265				
	n	7	7				
f1a overbank	average	0.033	0.383	0.043	csi	l	12
	std. dev.	0.058	0.247				
	maximum	0.100	0.550				
	minimum	0.000	0.100				
	median	0.000	0.500				
	n	3	3				
near background (f2 and some f1)	average	0.017	0.115	0.278	ms	ls	7
	std. dev.	0.011	0.087				
	maximum	0.035	0.250				
	minimum	0.002	0.024				
	median	0.017	0.110				
	n	6	6				

a. cs = coarse sand, ms = medium sand, vfs = very fine sand, csi = coarse silt

b. l = loam, sl = sandy loam, ls = loamy sand, s = sand

Plutonium concentrations in the coarse-grained channel facies sediment in P-4 are generally less than in associated overbank sediment, with the highest analysis of 16 pCi/g obtained from the c5 unit in P-4 West (sample location PU-0046) from an area close to the c6 locations with up to 170 pCi/g. All channel facies samples exceeding 3.2 pCi/g were collected from the c5 and c4b units in P-4 West and a subsurface layer in the c3 unit in P-4 East that is inferred to represent sediment of similar age (Table 3.3-10). Several subsurface samples from the c4b and c5 units are interpreted to represent sediment equivalent in age to the older c6 unit (Figures 3.3-14 and 3.3-15), and these samples are grouped with the c6 channel facies sediment. Averages and medians from this subset of the P-4 channel facies samples are 6.9 and 5.1 pCi/g (Table 3.3-11).

Plutonium concentrations are relatively low in the younger channel facies samples from reach P-4 (c1, c3, and c4a channel facies samples, and in a single f1 channel facies sample closely related to the c3 unit in P-4 East). Averages and medians for this combined data set are 1.3 and 1.1 pCi/g (Table 3.3-11). Note that several subsurface samples from the c3 and c4a units are interpreted to represent sediment equivalent in age to the older c6 unit (Figures 3.3-16 and 3.3-17), and these samples are grouped with the c6 channel facies sediment.

Samples from the channel facies of the c6 unit in P-4 and some subsurface samples from c3, c4a, c4b, and c5 that have similar plutonium concentrations and inferred age probably represent a combination of early post-1942 sediment and pre-1943 sediment. Field observations and analytical data indicate that pre-1943 sediment in many deposits near the post-1942 channel contain plutonium above the background value (Figures 3.3-14 to 3.3-17), and the most likely source of this plutonium is the vertical translocation of particles, such as clay, which have adsorbed plutonium. Because there is no reliable way to distinguish these pre-1943 and post-1942 sediments and because for purposes of calculating plutonium inventories and evaluating potential risk the age of the sediment is not important, these samples are combined into one bin. Averages and medians for this combined data set are 1.3 and 0.9 pCi/g (Table 3.3-11), similar to concentrations in the younger channel facies sediments.

3.3.5.2 Age and Particle Size Relations

Clear age trends are apparent in the plutonium data from reach P-4. Within the channel facies sediment, the highest plutonium concentrations are found in samples from the c5 unit in an area that was along or near the main channel in 1954, but which was abandoned by 1960 (Figure 2.3-21). It is notable that the wettest August since 1942 occurred in 1952, and it is possible that the distinctive c5 sand deposits were produced in one or more floods in 1952. Similar plutonium concentrations are found in the upper sediments of the c4b unit in areas occupied by the main channel after 1954 but abandoned by 1965. Sediments from units dating from 1965 to present (c4a, c3, c1b, and c1) yield lower concentrations of plutonium, and no trends are apparent during the last 30 years.

Figure 3.3-18 shows data on channel facies sediment from P-4 whose age is fairly well constrained from an examination of historical aerial photographs, along with data from active channel samples dating back to 1970 obtained from other projects in P-4 (e.g., LANL 1981, 6059) or from the environmental surveillance sample station at state road NM 502 east of P-4. Figure 3.3-18 shows that the peak plutonium concentrations in reach P-4 were probably attained within 10 years of the initial releases from TA-45 and that concentrations dropped rapidly after effluent releases ceased in 1964.

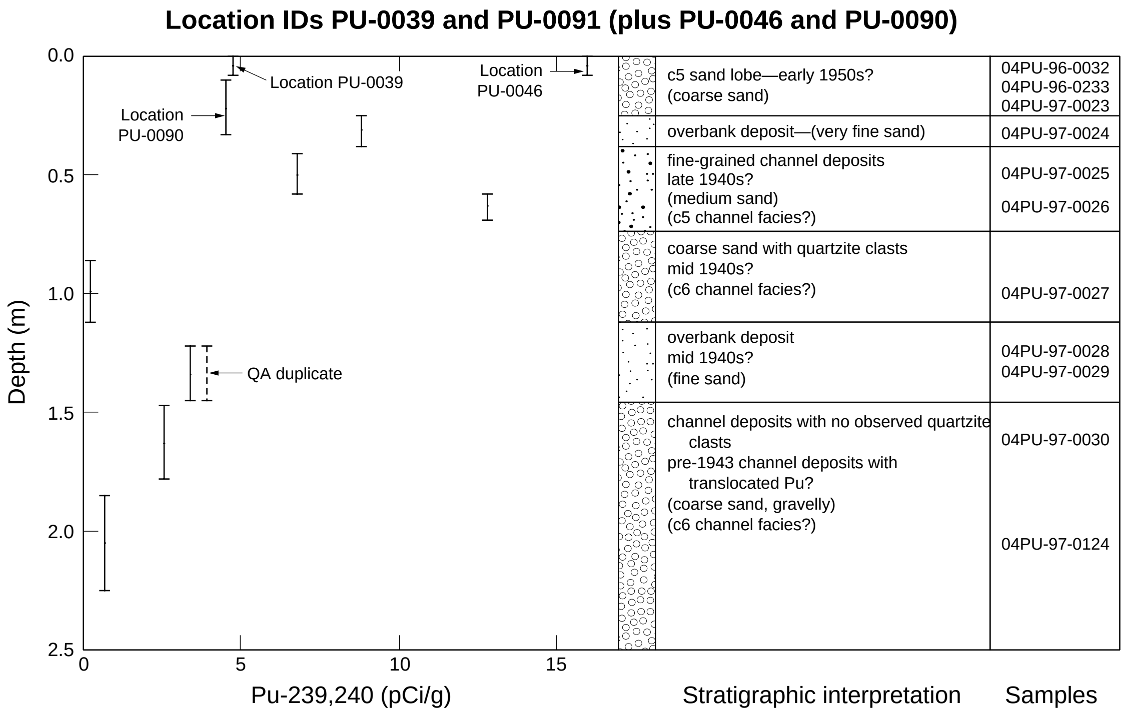


Figure 3.3-14. Depth variations in plutonium-239,240 concentration at sample sites in the c5 unit in reach P-4 West.

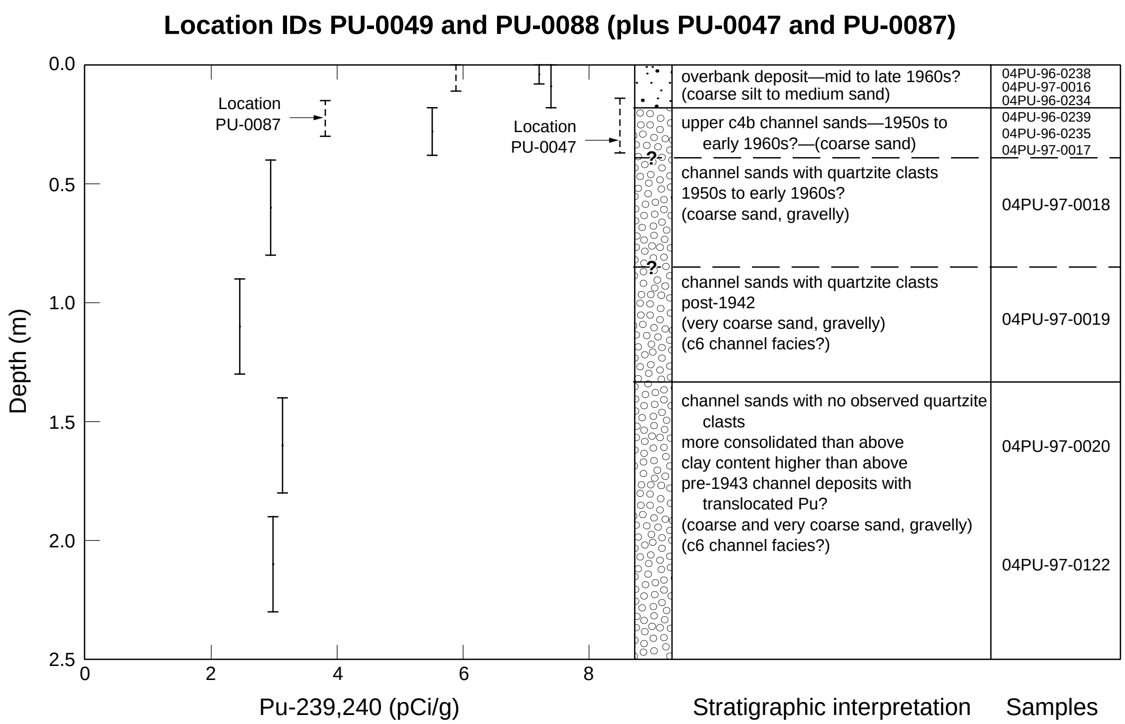


Figure 3.3-15. Depth variations in plutonium-239,240 concentration at sample sites in the c4b unit in reach P-4 West.

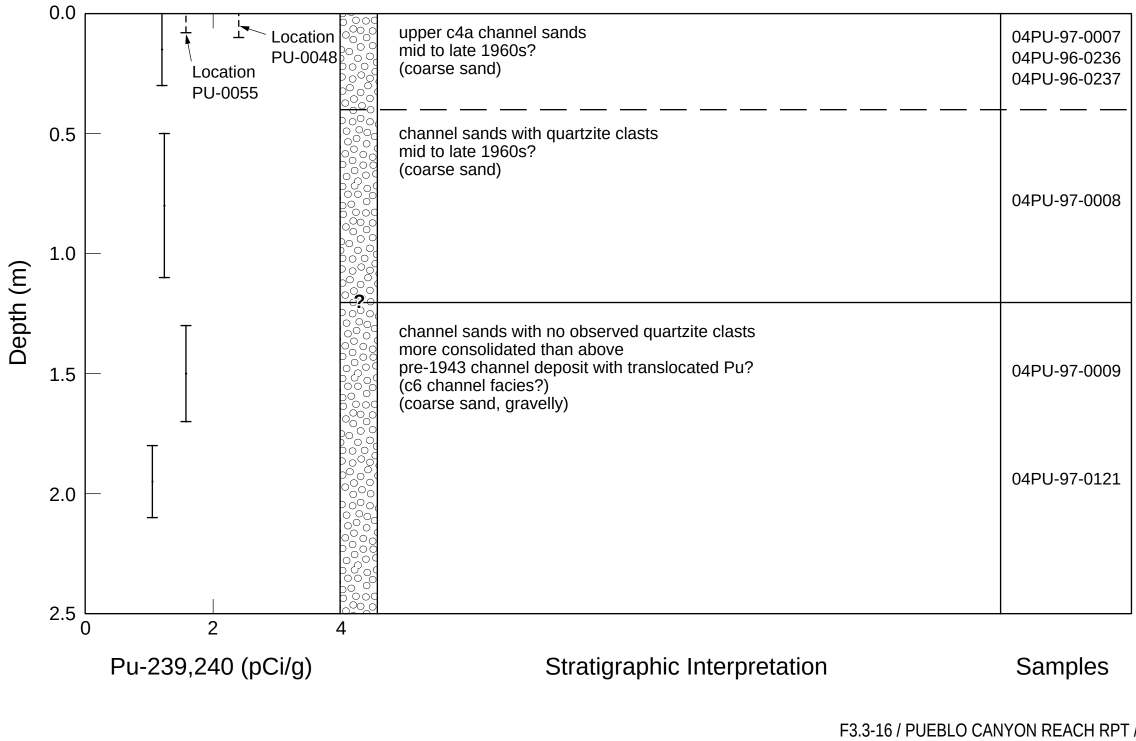


Figure 3.3-16. Depth variations in plutonium-239,240 concentration at sample sites in the c4b unit in reach P-4 West.

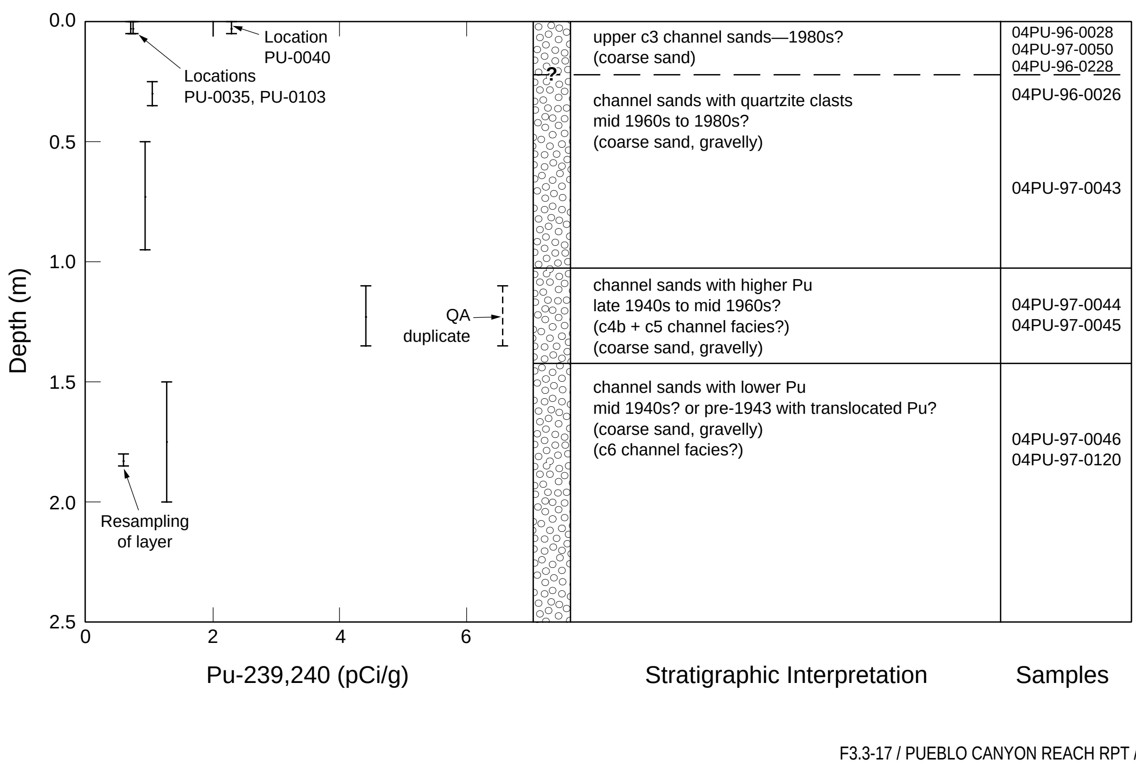
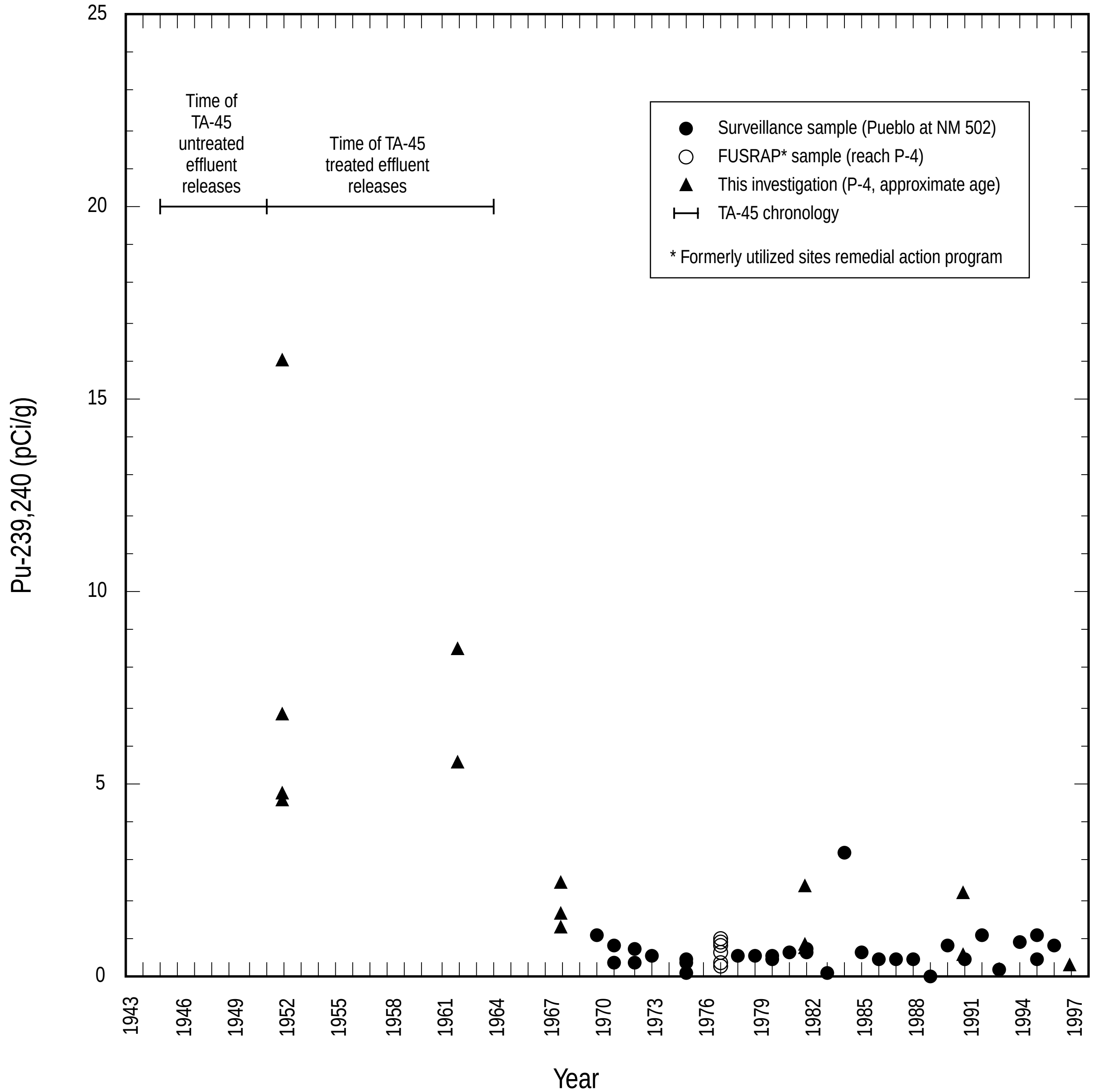


Figure 3.3-17. Depth variations in plutonium-239,240 concentration at sample sites in the c3 unit in reach P-4 East.



F3.3-18 / PUEBLO CANYON REACH RPT / 102298

Figure 3.3-18. Relation of plutonium-239,240 concentration to age from channel facies sediment samples collected in reach P-4 and from the environmental surveillance station in Pueblo Canyon at state road NM 502.

Sediment samples in P-4 show the same general increases in plutonium concentration with decreases in particle size that are seen in P-1 East and P-2 West (Figure B3-4). These relationships hold for both the relatively old sediments (c4b and c5 channel facies sediment and related c6 overbank facies sediment) and for the younger sediments (c1, c3, and c4a channel facies and f1 overbank facies).

3.3.5.3 Plutonium Inventory

Reach P-4 has the largest estimated inventory of plutonium-239,240 in any of the Pueblo Canyon reaches, associated with a combination of exceptionally large volumes of post-1942 sediment and higher plutonium concentrations than in the closest upstream reaches (P-3 and P-2 East). Total estimated plutonium in P-4 West, 305 mCi/km, is approximately twice that in P-4 East, 149 mCi/km, because of the large volumes of sediment dating from the mid-1940s to the mid-1960s. Most of the estimated plutonium-239,240 inventory in reach P-4 is associated with channel facies sediment, 69% in P-4 West and 70% in P-4 East (Table 3.3-12), more than in any upstream reach. Most of the plutonium estimated to be stored in P-4 West is divided between c6 (26%), c5 (23%), c4a (22%), and c4b (20%). In P-4 East the most important unit is c3, with an estimated 61% of the total inventory. In both subreaches less than 25% of the plutonium is stored in sites considered to be potentially subject to remobilization, with most plutonium residing in areas presently removed from the active channel.

Uncertainties in the estimates of plutonium inventory in reach P-4 are believed to be relatively high as compared with other Pueblo Canyon reaches. These uncertainties are in part related to the difficulty in determining the average thickness of plutonium-bearing sediment beneath the extensive channel units and in part to the vertical variations in plutonium concentration related to age variations within these deposits. Translocation of plutonium associated with organic colloids and/or clay particles by subsurface water may be widespread (Section 3.3.5.1), resulting in above-background levels of plutonium in large volumes of pre-1943 channel sediment. The high variability in plutonium concentration among samples collected from the oldest channel and overbank deposits also contributes to uncertainties in total plutonium inventory.

TABLE 3.3-12

ESTIMATED PLUTONIUM INVENTORY IN REACH P-4

Sediment Facies	Geomorphic Unit	Section	Area (m^2)	Estimated Average Thickness (m)	Estimated Volume (m^3)	Estimated Fraction <2 mm	Estimated Density (g/cm^3)	Estimated Average Pu-239,240 Concentration (pCi/g)	Estimated Pu-239,240 Inventory (mCi)	Percent of Total Subreach Inventory	Percent Potentially Susceptible to Remobilization	Estimated Inventory Most Susceptible to Remobilization (mCi)	Percent of Total Subreach Inventory Susceptible to Remobilization
P-4 West													
Channel	c1,1b	Lower	3505	0.45	1577	0.8	1.23	1.32	2.0	1%	100%	2.0	1%
Channel	c2a,b,c	Lower	6123	0.45	2755	0.8	1.23	1.32	3.6	2%	100%	3.6	2%
Channel	c3	Lower	276	0.45	124	0.8	1.23	1.32	0.2	0%	100%	0.2	0%
Channel	c4a	Upper channel	8064	1.1	8871	0.8	1.23	1.32	11.5	7%	10%	1.2	1%
Channel	c4a	Middle channel	8064	0.2	1613	0.8	1.23	6.95	11.0	7%	10%	1.1	1%
Channel	c4a	Lower channel	8064	1.1	8871	0.8	1.23	1.27	11.1	7%	10%	1.1	1%
Channel	c4b	Upper channel	3791	0.9	3412	0.8	1.23	6.95	23.3	15%	10%	2.3	1%
Channel	c4b	Lower channel	3791	1.5	5686	0.8	1.23	1.27	7.1	4%	10%	0.7	0%
Channel	c5	Upper channel	4296	0.9	3866	0.8	1.23	6.95	26.4	17%	10%	2.6	2%
Channel	c5	Lower channel	4296	1.5	6443	0.8	1.23	1.27	8.1	5%	10%	0.8	1%
Channel	c6	Lower	4897	0.8	3918	0.8	1.23	1.27	4.9	3%	10%	0.5	0%
Subtotal			**55167**		**47136**				**109.3**	**69%**		**16.1**	**10%**
Overbank	c1,1b	Upper	3505	0.05	175	0.85	1.04	5.99	0.9	1%	100%	0.9	1%
Overbank	c2a,b,c	Upper	6123	0.05	306	0.85	1.04	5.99	1.6	1%	100%	1.6	1%
Overbank	c3	Upper	276	0.05	14	0.85	1.04	5.99	0.1	0%	100%	0.1	0%
Overbank	c4a	Upper	8064	0.05	403	0.85	1.04	5.99	2.1	1%	10%	0.2	0%
Overbank	c4b	Upper	3791	0.1	379	0.85	1.04	5.99	2.0	1%	10%	0.2	0%
Overbank	c5	Upper	4296	0.1	430	0.85	1.04	5.99	2.3	1%	10%	0.2	0%

TABLE 3.3-12 (continued)

ESTIMATED PLUTONIUM INVENTORY IN REACH P-4

Sediment Facies	Geomorphic Unit	Section	Area (m^2)	Estimated Average Thickness (m)	Estimated Volume (m^3)	Estimated Fraction < 2 mm	Estimated Density (g/cm^3)	Estimated Average Pu-239,240 Concentration (pCi/g)	Estimated Pu-239,240 Inventory (mCi)	Percent of Total Subreach Inventory	Percent Potentially Susceptible to Remobilization	Estimated Inventory Most Susceptible to Remobilization (mCi)	Percent of Total Subreach Inventory Susceptible to Remobilization
P-4 West													
Overbank	c6	Upper	4897	0.2	979	0.93	1.04	37.83	35.8	23%	10%	3.6	2%
Overbank	f1	All	12862	0.05	643	0.94	1.04	5.99	3.8	2%	10%	0.4	0%
Overbank	f1a	All	5744	0.15	862	0.91	1.04	0.38	0.3	0%	0%	0.0	0%
Overbank	f2	All	5220	0.01	52	0.94	1.04	5.99	0.3	0%	0%	0.0	0%
Subtotal					**4243**				**49.3**	**31%**		**7.2**	**5%**
Total					**51379**				**158.5**	**100%**		**23.4**	**15%**
P-4 East													
Channel	c1,1b	Lower	14154	0.45	6369	0.8	1.23	1.32	8.3	9%	100%	8.3	9%
Channel	c2a,b,c	Lower	1357	0.45	611	0.8	1.23	1.32	0.8	1%	100%	0.8	1%
Channel	c3	Upper channel	13159	1	13159	0.8	1.23	1.32	17.1	19%	10%	1.7	2%
Channel	c3	Middle channel	13159	0.2	2632	0.8	1.23	6.95	18.0	20%	10%	1.8	2%
Channel	c3	Lower channel	13159	1	13159	0.8	1.23	1.27	16.4	18%	10%	1.6	2%
Channel	f1	Lower	31570	0.05	1579	0.8	1.23	1.32	2.1	2%	10%	0.2	0%
Subtotal					**37508**				**62.7**	**70%**		**14.4**	**16%**
Overbank	c1,1b	Upper	14154	0.05	708	0.85	1.04	5.99	3.7	4%	100%	3.7	4%
Overbank	c2a,b,c	Upper	1357	0.05	68	0.85	1.04	5.99	0.4	0%	100%	0.4	0%
Overbank	c3	Upper	13159	0.05	658	0.85	1.04	5.99	3.5	4%	10%	0.3	0%
Overbank	f1	Upper	31570	0.1	3157	0.94	1.04	5.99	18.5	21%	10%	1.8	2%
Overbank	f2	Upper	15038	0.01	150	0.94	1.04	5.99	0.9	1%	0%	0.0	0%
Subtotal					**4741**				**27.0**	**30%**		**6.3**	**7%**
Total					**42249**				**89.6**	**100%**		**20.7**	**23%**

4.0 REVISED CONCEPTUAL MODEL

A key part of the technical approach for the evaluation of contamination in Pueblo Canyon sediments, as presented in Chapter 5 of the work plan (LANL 1995, 50290), involved the collection of data to test hypotheses concerning the nature, distribution, and transport of contaminants associated with sediment. These hypotheses comprise components of a preliminary conceptual model and were developed based on results of prior investigations in Pueblo Canyon and elsewhere, as discussed in Section 4.2 of the work plan. Because of the significant length of canyon floor affected by the transport and deposition of contaminated sediments and because of the complexity of sediment transport processes that have been operating since 1942, the validation and refinement of this conceptual model is necessary to perform a defensible quantitative evaluation of risk in the sampled reaches, to qualitatively evaluate risk in intervening unsampled areas, and to evaluate the future redistribution of contaminants and associated impacts.

This section presents the current conceptual model of contamination in Pueblo Canyon sediments, which has been revised and refined from the preliminary conceptual model presented in Section 4.2 of the work plan (LANL 1995, 50290) based on the results of the investigations in reaches P-1, P-2, P-3, and P-4 as discussed in Sections 2 and 3 of this report. This conceptual model includes discussions of the general nature and extent of contamination within the sediments, controlling factors for present-day contaminant distribution and variations in contaminant levels, geomorphic processes that redistribute these contaminants, and inferences about the fate and future transport of these contaminants.

4.1 Nature and Extent of Contamination

4.1.1 Analytes above Background Values

A series of analytes are present within the sediments in Pueblo Canyon at levels above background values and are considered to be chemicals of potential concern (COPCs), as discussed in Section 3.2 and summarized in Table 4.1-1. The most significant contaminants are radionuclides that can be associated with releases from former Technical Area (TA) -45 into Acid Canyon. Americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90, and tritium were all identified as COPCs in this investigation. Uranium-234, uranium-235, and uranium-238 have also been reported above background values in Acid Canyon in prior investigations (LANL 1981, 6059; LANL 1996, 54468), but these analytes were not detected above background values in this investigation; their low levels are inferred to record a combination of the limited size of the initial releases and dilution with other sediment in Acid and Pueblo Canyons.

TABLE 4.1-1

SUMMARY OF PUEBLO CANYON COPCs

COPC and Units	Background Value or Estimated Quantitation Limit	Maximum Result[a]	Subreach with Maximum Result[a]	Geomorphic Unit and Sediment Facies with Maximum Result[a]	Inferred Source(s)
Radionuclides (pCi/g)					
Americium-241	0.04	10.671	P-1 East	c2b, overbank	TA-45
Cesium-137	0.90	1.53	P-1 East	f1, overbank	Fallout (+ TA-45?)
Plutonium-238	0.006	2.078	P-1 East	c2b, overbank	TA-45
Plutonium-239,240	0.068	502.01	P-1 East	c2b, overbank	TA-45
Strontium-90	1.03	1.4	P-1 East	f1, overbank	TA-45 (+ fallout)
Tritium	0.093	1.21	P-1 East	c2b, overbank	TA-45
Inorganic Chemicals (mg/kg)					
Antimony	0.83	[4.9]	[P-1 and P-4]	[Varied]	Possibly background
Cadmium	0.4	0.92	P-1 East	c2b, overbank	PCWWTP[b] + TA-45 (?)
Copper	11.2	31.5	P-2 West	c2, overbank	Possibly many sources
Lead	19.7	77.3	P-1 East	c2b, overbank	PCWWTP + TA-45 + nps[c] (?)
Mercury	0.1	0.65	P-1 East	c2b, overbank	PCWWTP + TA-45 (?)
Selenium	0.3	0.98 [1.1]	P-2 West [P-1]	c2b, overbank	Unknown (multiple sources? background?)
Silver	1.0	1.7	P-1 West	c2, overbank	PCWWTP + TA-45 (?)
Zinc	60.2	113	P-1 East	c2b, overbank	PCWWTP + TA-45 (?)
Organic Chemicals (mg/kg)					
Aroclor-1254	0.033	0.238	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Aroclor-1260	0.033	0.117	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Aldrin	0.033	0.00211	P-1 East	c2, overbank	Unknown (multiple sources? nps?)
δ-BHC	0.033	0.00197 [0.0023]	P-1 East [P-3 W]	c2b, overbank	Unknown (multiple sources? nps?)
α-Chlordane	0.0165	0.00497	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
γ-Chlordane	0.0165	0.00211 [0.0023]	Acid Cyn [P-3 W]	c1, channel	Unknown (multiple sources? nps?)

a. Values in brackets indicate that the maximum result is reported as a nondetect.
b. PCWWTP = Pueblo Canyon Wastewater Treatment Plant
c. nps = nonpoint sources

TABLE 4.1-1 (continued)

SUMMARY OF PUEBLO CANYON COPCs

COPC and Units	Background Value or Estimated Quantitation Limit	Maximum Result[a]	Subreach with Maximum Result[a]	Geomorphic Unit and Sediment Facies with Maximum Result[a]	Inferred Source(s)
Organic Chemicals (mg/kg)					
4,4'-DDT	0.033	0.00599	Acid Cyn	c1, channel	Unknown (multiple sources? nps[b]?)
Acenaphthene	0.33	0.219 [0.344]	P-4 West [P-4 W]	c5, channel	Unknown (multiple sources? nps?)
Acenaphthylene	0.33	0.44	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Anthracene	0.33	0.369	P-4 West	c5, channel	Unknown (multiple sources? nps?)
Benz(a)anthracene	0.33	1.0	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Benzo(a)pyrene	0.33	1.7	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Benzo(b)fluoranthene	0.33	2.5	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Benzo(g,h,i)perylene	0.33	0.86	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Benzo(k)fluoranthene	0.33	0.95	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Benzoic acid	0.33	0.75 [3.3]	Acid Cyn [P-1 E]	c1, channel	Unknown (multiple sources? nps?)
Bis(2-ethylhexyl)phthalate	0.33	2.8	P-1 West	c2, overbank	Unknown (multiple sources? nps?)
Carbazole	0.33	0.18 [0.34]	P-1 East [P-1 E]	c2b, overbank	Unknown (multiple sources? nps?)
Chrysene	0.33	1.2	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Di-n-octylphthalate	0.33	0.094 [0.66]	P-4 West [P-1 E]	f1, overbank	Unknown (multiple sources? nps?)
Dibenz(a,h)anthracene	0.33	0.28 [0.66]	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Dibenzofuran	0.33	0.18 [0.344]	P-4 West [P-4 W]	c5, channel	Unknown (multiple sources? nps?)
Fluoranthene	0.33	1.9	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
Fluorene	0.33	0.294 [0.344]	P-4 West [P-4 W]	c5, channel	Unknown (multiple sources? nps?)
Indeno(1,2,3-cd)pyrene	0.33	0.88	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)
2-Methylnaphthalene	0.33	0.167 [0.66]	P-4 West [P-1 E]	c5, channel	Unknown (multiple sources? nps?)
Naphthalene	0.33	0.374	P-4 West	c5, channel	Unknown (multiple sources? nps?)
Phenanthrene	0.33	1.505	P-4 West	c5, channel	Unknown (multiple sources? nps?)
Pyrene	0.33	2.2	P-1 East	c2b, overbank	Unknown (multiple sources? nps?)

a. Values in brackets indicate that the maximum result is reported as a nondetect.

b. nps = nonpoint sources

Americium-241 and plutonium-238 are generally well correlated with plutonium-239,240 in Pueblo Canyon sediment samples, indicating that they are collocated and hence share similar histories of release and subsequent transport. However, both americium-241 and plutonium-238 occur at relatively low concentrations compared with plutonium-239,240 (averaging approximately 2.6% and 0.5% of the plutonium-239,240 values, respectively). A correlation of tritium with plutonium-239,240 may also exist, but this apparent correlation is controlled by collocation of the highest tritium value and the highest plutonium-239,240 value and may not be reliable. Cesium-137 and strontium-90 were both found above background values in a single sample from fine-grained f1 sediments in P-1 with relatively low concentrations of plutonium-239,240. These radionuclides may be correlated with each other but are not correlated with plutonium-239,240 and the other radionuclide COPCs. The lack of correlation of cesium-137 with plutonium-239,240 and its low concentrations in Pueblo Canyon sediments suggests that total releases of cesium-137 from TA-45 were small and that cesium-137 in Pueblo Canyon is dominantly derived from worldwide fallout. The low levels of cesium-137 in Pueblo Canyon sediments, as represented by a small but statistically significant concentration shift, and the lack of correlation of cesium and plutonium are consistent with results of previous investigations (Nyhan et al. 1982, 7164). Strontium-90 in reach P-1 displays a statistical shift from background that is less than 50% of the background value (or less than 0.5 pCi/g). This small but statistically significant shift indicates recognizable releases from TA-45, although total releases were apparently small.

Inorganic chemicals identified as COPCs in this investigation include antimony, cadmium, copper, lead, mercury, selenium, silver, and zinc (Table 4.1-1). Most detected concentrations of these metals are less than background values, indicating that contaminant releases were relatively small. Five of the inorganic COPCs (cadmium, lead, mercury, silver, and zinc) appear to have primary sources in the upper Pueblo Canyon watershed and to have their highest concentrations in reach P-1. Relative to background values, the most significant inorganic COPCs are mercury and lead, at roughly seven times and four times background values, respectively. These metals are apparently not collocated with plutonium-239,240 and may have been derived from a variety of sources in Acid Canyon and upper Pueblo Canyon, including the Pueblo Canyon Wastewater Treatment Plant (WWTP), TA-45, and perhaps non-Laboratory sources in the Los Alamos townsite.

The origin and distribution of the other inorganic COPCs in Pueblo Canyon sediments (antimony, copper, and selenium) are not certain. Antimony was retained as a COPC solely because detection limits for some samples are above background values, but the lack of any detected antimony results suggests that antimony was not released into Pueblo Canyon. Copper has a few results above the background value, but no pattern is discernible in its physical distribution; the copper in Pueblo Canyon sediments may be derived from a variety of sources. Selenium has a series of detected sample results and nondetect values above the background value, but these are all close to the background value, and the selenium results may not represent actual contaminant releases.

Twenty-nine organic chemicals were identified as COPCs in this investigation (Table 4.1-1), as discussed in Section 3, but reported concentrations for all these analyses are relatively low, and their origin and distribution in Pueblo Canyon sediments are uncertain. The frequency of detects is highest in reach P-1, and most of the maximum detected sample results for these inorganic COPCs were obtained from P-1, suggesting sources in the upper watershed; however, these analytes are often not collocated with radionuclide or inorganic COPCs, suggesting different sources for the different suites of COPCs. There may be partial collocation of some subsets of the inorganic COPCs because the maximum detected values for 11 of these COPCs were obtained from one sediment sample from P-1 East, and the maximum detected values for 8 of these COPCs were obtained from one sediment sample from P-4 West. However, the data set for the inorganic COPCs is small, limiting confidence in any inferences about their distribution.

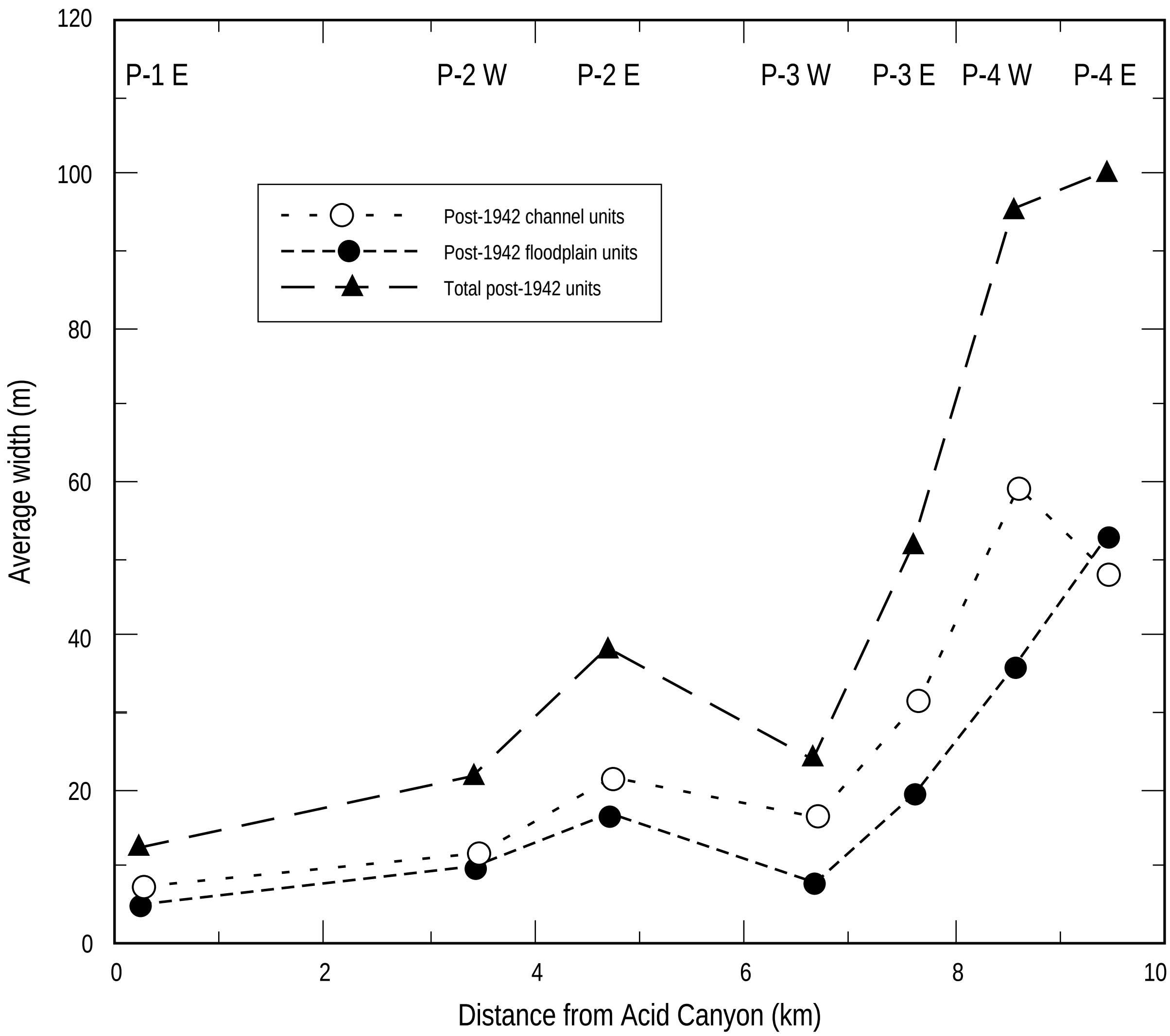
4.1.2 Horizontal and Vertical Extent

The horizontal and vertical extent of contaminated sediments in Pueblo Canyon have been defined largely through geomorphic mapping, which identified the probable distribution of post-1942 sediment; analytical results from sediment samples were used to confirm and refine the mapping during the phased field investigations. Plutonium-239,240 and other contaminants have been distributed by floods along the full length of Pueblo Canyon downstream from Acid Canyon, a stream distance of more than 10 km, and have been distributed laterally from several meters to more than 100 m away from the present stream channel. The lateral distribution varies considerably depending on the local morphology of the canyon floor, and the width of the area affected by post-1942 floods generally increases downstream (Figures 4.1-1 and 4.1-2). The area inundated by post-1942 floods and containing sediment with plutonium-239,240 above the background value of 0.068 pCi/g averages approximately 12 m wide in reach P-1, 22 to 52 m wide in reaches P-2 and P-3, and 95 to 100 m wide in reach P-4. The combined width of all channel units in a reach is typically greater that the width of floodplain units, although both show similar increases between P-1 and P-4 (Figure 4.1-1).

The vertical extent of contamination in Pueblo Canyon sediments ranges from depths of less than 5 cm to at least 4 m. The thinnest layers of contaminated sediment occur on floodplains that were probably only briefly inundated by one or more floods since 1942. In contrast, areas of active and abandoned post-1942 channels are commonly underlain by 1 m or more of sediment containing plutonium-239,240 above background values. The plutonium in these channel units is probably dominated by plutonium adsorbed to sediment particles and deposited by post-1942 floods, thus being restricted to post-1942 sediment, but also includes plutonium that has translocated into deeper sediments. Evidence for vertical translocation of plutonium is provided by the presence of plutonium above background values in probable pre-1943 sediment as discussed in Section 3.3, including sediment at a depth of 4 m in core from alluvial well PAO-1 in reach P-3 East (Figure 3.3-8). Samples from four deep sections through abandoned channel units in reach P-4 also confirmed the presence of plutonium to depths greater than 2 m (Figures 3.3-13 to 3.3-17). The processes controlling the translocation of this plutonium are not fully understood but may include plutonium adsorbed to clay-sized particles and/or organic colloids and transported by alluvial groundwater originating from wastewater treatment plants within the Pueblo Canyon watershed. However, most of the plutonium and the highest concentrations in every geomorphic unit occur within the upper 0.5 to 1.5 m of the surface in sediment deposited by post-1942 floods.

4.2 Variations in Contamination

The present distribution of plutonium and other COPCs and variations in contaminant concentration in Pueblo Canyon sediments are largely controlled by sediment transport processes that have been operating during the past 55 years. Thus sediment transport processes also affect spatial variations in any present or future risk that may be associated with these contaminants. Key components of the preliminary conceptual model that have been confirmed by this investigation include the occurrence of the highest concentrations of plutonium in areas closest to the source (reach P-1 East), in relatively fine-grained sediment deposits, and in relatively old sediments (pre-1965). This investigation also confirmed previous conclusions that the largest part of the total plutonium inventory in Pueblo Canyon occurs in the eastern part of the canyon (reach P-4). However, some results of this investigation reveal more complexity in the distribution of plutonium than was proposed in prior investigations, including the occurrence of relatively high concentrations of plutonium in some sediment layers in the eastern canyon many kilometers from the source and relatively low concentrations in some upstream areas. Variations in contaminant concentration as pertains to evaluating risk and understanding important transport processes are discussed in the following sections.



F4.1-1 / PUEBLO CANYON REACH RPT / 102398

Figure 4.1-1. Variations in the width of post-1942 channel and floodplain geomorphic units in the Pueblo Canyon reaches.

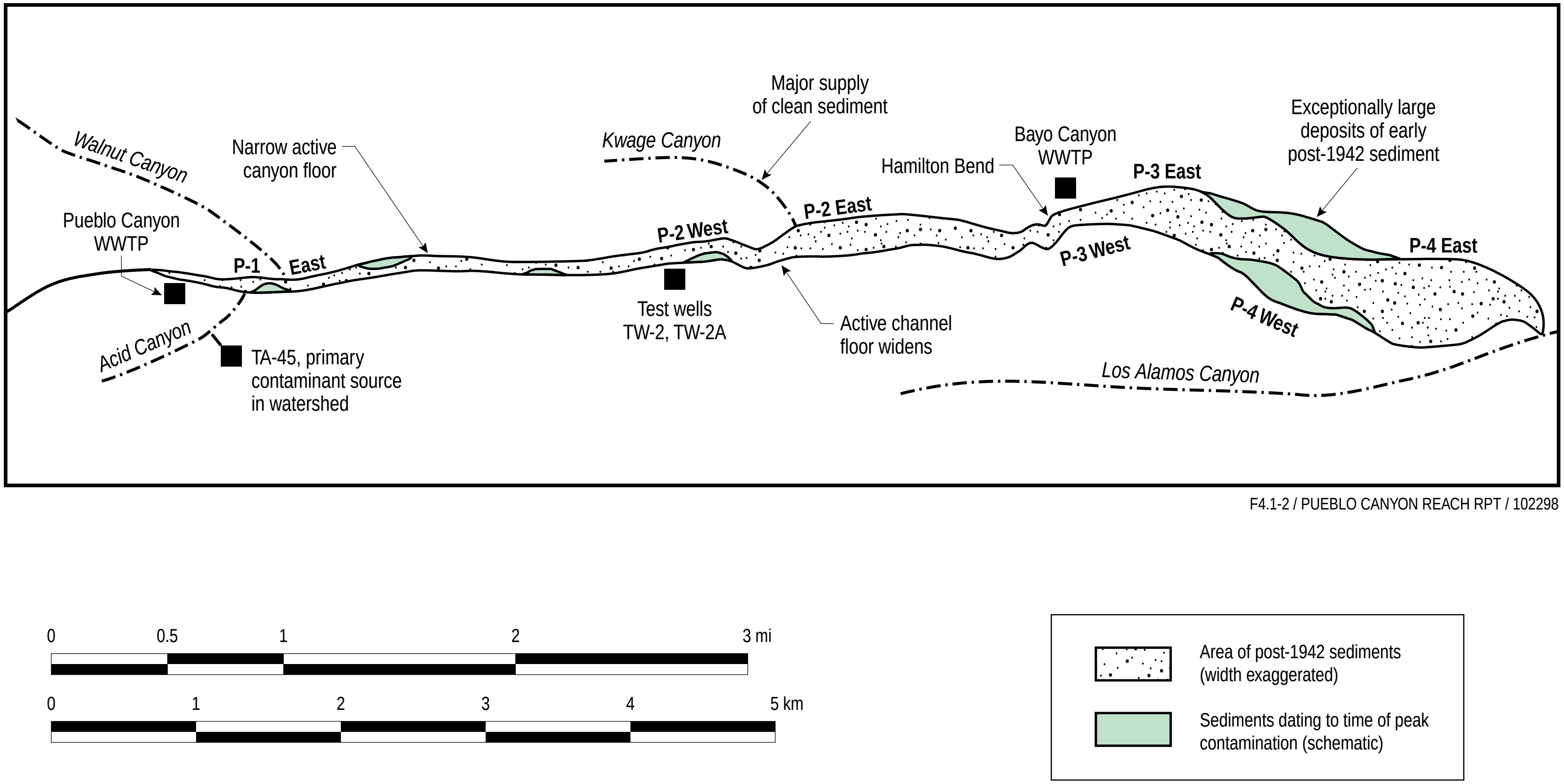


Figure 4.1-2. Schematic map of Pueblo Canyon showing variations in the width of canyon floor inundated by post-1942 floods and spatial variations in the area occupied by early post-1942 sediment deposits.

4.2.1 Relations to Particle Size Variations

Variations in particle size characteristics between sediment deposits of similar age have a major influence on vertical and horizontal variations in plutonium concentrations in Pueblo Canyon and also have important implications for evaluating risk. In every reach, the maximum and average plutonium concentrations are higher in the relatively fine-grained overbank facies sediment deposits than in associated coarse-grained channel facies sediment deposits, as discussed in Section 3.3. The higher plutonium concentrations in overbank facies sediment are also apparent in volume-weighted averages that combine data from all units in each reach (Table 4.2-1, Figure 4.2-1). Within sediments of similar age in each reach, trends of increasing plutonium concentration with increasing percentages of clay-sized particles and/or silt and clay particles are also evident (Section 3.3 and Figures B3-1 to B3-4), which explains some of the variation in plutonium concentration within sediments in a reach. The poorest relations between plutonium concentration and particle size are present in the reaches with the lowest concentrations of plutonium (reaches P-2 East and P-3; Figures B3-2 and B3-3), which may in part be due to the mixing of variable amounts of uncontaminated sediment supplied from Kwage Canyon with contaminated sediment originating from upstream reaches in Pueblo Canyon. However, in reaches where plutonium concentrations are relatively high, particle size trends in plutonium concentration are more apparent (reaches P-1 East, P-2 West, and P-4; Figures B3-1, B3-2, and B3-4), including both relatively old and relatively young subsets of the samples. Thus the results of this investigation are consistent with previous investigations that showed the influence of particle size variations on contaminant concentrations (e.g., Nyhan et al. 1976, 11747) and support the collection of data on particle size distribution in sediment samples to understand the basis for variations in contamination. Importantly, plutonium concentrations in the respirable fraction (< 10 micron size fraction, including fine silt and clay-sized particles) will be higher than those measured in a bulk sediment sample where less than 20% of the material is within this size range. The smaller size fractions will also be more likely to adhere to skin and potentially be ingested.

4.2.2 Age Trends

Clear relations between plutonium concentration and sediment age are present in Pueblo Canyon, and the largest variations in contaminant concentration in each reach can be attributed to variations in the age of the sampled sediment deposits. The strongest relations between sediment age and plutonium concentration were obtained in reach P-4, in part because of the excellent age control for a series of geomorphic units that was provided by examination of historic aerial photographs. In reach P-4 the channel facies sediment with the highest plutonium concentration is dated to the period between 1942 and 1965, particularly a large sand deposit (c5 unit in P-4 West) that probably dates to the early 1950s (Figure 3.3-18). Notably, the highest plutonium concentration measured east of P-1 East was from a fine-grained overbank facies sediment layer in P-4 West that may also date to this same time period based on its close proximity to the location of the main channel in the 1950s. In addition, combined data from this investigation and prior investigations demonstrate that plutonium concentrations in active channel sands of reach P-4 have been relatively low for the past 30 to 35 years (Figure 3.3-18), and similar or lower concentrations can be expected to exist in the future.

TABLE 4.2-1

SUMMARY OF GEOGRAPHIC AND RADIOLOGICAL CHARACTERISTICS OF PUEBLO CANYON REACHES

Part 1

Reach	Approx. Stream Elevation, Upstream End (ft)	Approx. Distance From Acid Canyon (km)[a]	Approx. Length Sampled Reach (km)	Approx. Length Unsampled Reach (km)	Estimated Volume of Post-1942 Channel Facies Sediment (m^3/km)	Estimated Volume of Post-1942 Overbank Facies Sediment (m^3/km)	Estimated Total Pu-239,240 Inventory (Sampled Reaches) (mCi)	Estimated Total Pu-239,240 Inventory (Unsampled Reaches) (mCi)[b]	Estimated Total Pu-239,240 Inventory, Channel Facies (Sampled Reaches) (mCi/km)
P-1 West	6950	-0.08	0.08						
P-1 East	6943	0	0.51		3365	3586	42.3		14.7
P-1 to P-2	6892	0.51		2.69				217.8	
P-2 West	6640	3.2	0.51		12114	5653	40.3		18.6
P-2 unsampled	6615	3.71		0.78				61.6	
P-2 East	6583	4.49	0.46		38391	8941	17.1		16.1
P-2 to P-3	6561	4.95		1.46				58.1	
P-3 West	6500	6.41	0.51		28665	5329	21.6		26.7
P-3 unsampled	6484	6.92		0.45				25.6	
P-3 East	6461	7.37	0.54		53609	15885	38.5		37.8
P-3 to P-4	6432	7.91		0.40				75.3	
P-4 West	6410	8.31	0.52		90646	8160	158.6		210.2
P-4 unsampled	6379	8.83		0.33				75.0	
P-4 East	6363	9.16	0.60		62513	7902	89.7		104.5
P-4 to LA Cyn	6326	9.76		0.73				109.1	
Confluence	6262	10.49							
Total			**3.65**	**6.84**			**408.1**	**622.6**	

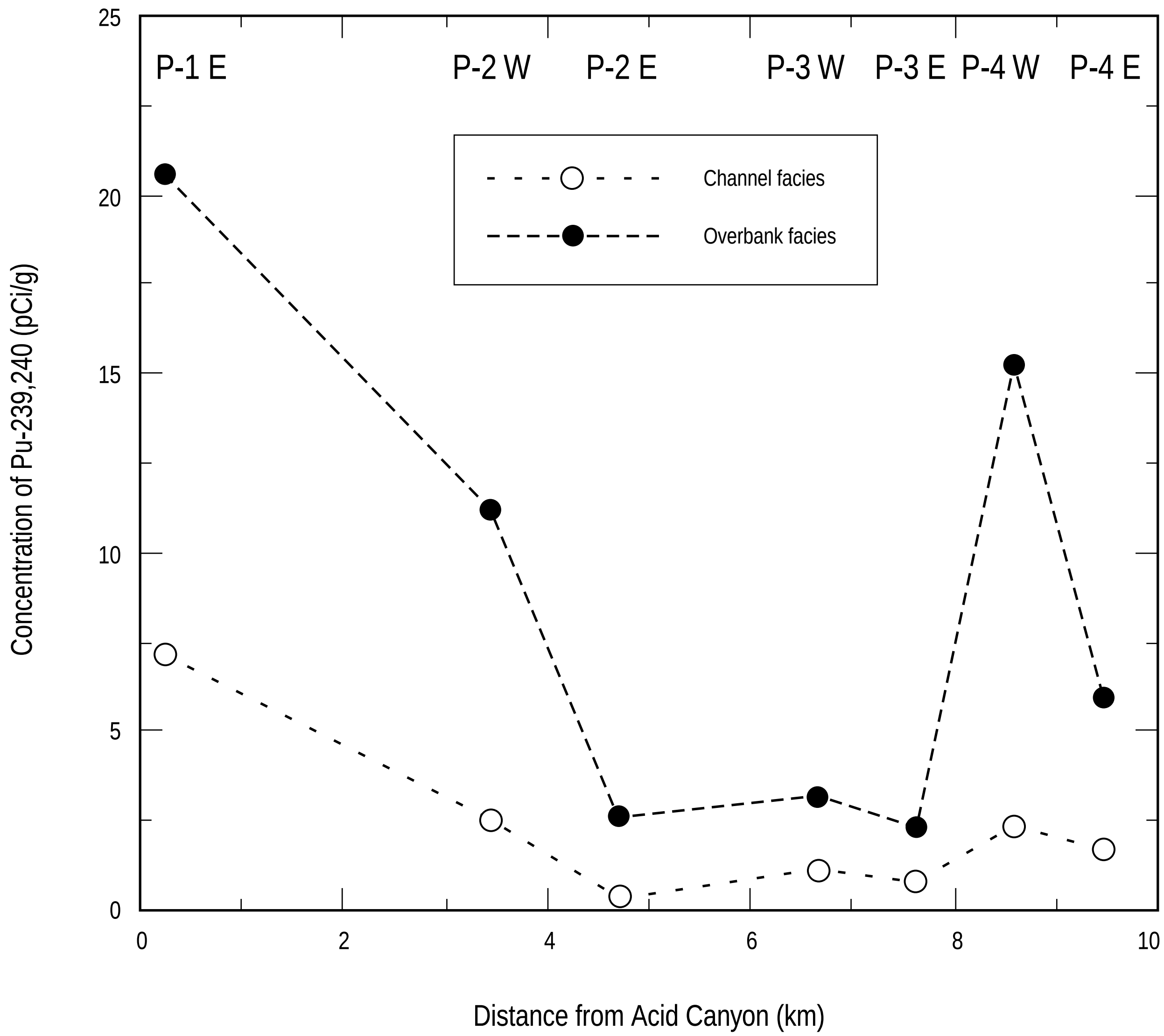
a. Approximate distances from Acid Canyon measured along the stream channel as depicted on 1:1200 scale FIMAD maps with 2-ft contour intervals

b. Preliminary estimate of inventory in unsampled reaches assumes either average inventories (mCi/km) of bounding sampled reaches, or same inventory as adjacent reach near major tributary junctions.

TABLE 4.2-1 (continued)

SUMMARY OF GEOGRAPHIC AND RADIOLOGICAL CHARACTERISTICS OF PUEBLO CANYON REACHES

Part 2							
Reach	**Estimated Total Pu-239,240 Inventory, Overbank Facies (Sampled Reaches) (mCi/km)**	**Estimated Total Pu-239,240 Inventory (Sampled Reaches) (mCi/km)**	**Estimated Average Pu-239,240 Concentration in Post-1942 Channel Facies Sediment (pCi/g)**	**Estimated Average Pu-239,240 Concentration in Post-1942 Overbank Facies Sediment (pCi/g)**	**Estimated Pu-239,240 Inventory Susceptible to Remobilization (Sampled Reaches) (mCi)**	**Estimated Pu-239,240 Inventory Susceptible to Remobilization (Unsampled Reaches) (mCi)**	**Estimated Pu-239,240 Inventory Susceptible to Remobilization (Sampled Reaches) (mCi/km)**
P-1 West							
P-1 East	68.2	82.9	7.14	20.55	24.3		47.6
P-1 to P-2						130.8	
P-2 West	60.4	79.0	2.51	11.21	25.3		49.6
P-2 unsampled						38.7	
P-2 East	21.1	37.2	0.38	2.55	5.7		12.4
P-2 to P-3						33.2	
P-3 West	15.7	42.4	1.14	3.13	16.9		33.1
P-3 unsampled						18.1	
P-3 East	33.5	71.3	0.85	2.36	25.5		47.2
P-3 to P-4						18.4	
P-4 West	94.8	305.0	2.36	15.21	23.4		45.0
P-4 unsampled						13.1	
P-4 East	45.0	149.5	1.70	5.99	20.7		34.5
P-4 to LA Cyn						25.2	
Confluence							
Total					**141.8**	**252.4**	



F4.2-1 / PUEBLO CANYON REACH RPT / 102398

Figure 4.2-1. Estimated average plutonium-239,240 concentration in Pueblo Canyon sediments.

Relations between plutonium concentration and sediment age are not as well defined in the other reaches in Pueblo Canyon relative to P-4, in part related to less precise age constraints on geomorphic units. However, data from P-1, P-2, and P-3 are also consistent with the highest concentrations of plutonium occurring relatively early in the post-1942 period and concentrations being stable or declining during the past few decades. For example, the highest plutonium concentrations found in Pueblo Canyon occur in a subsurface layer in P-1 East that is inferred to be contemporaneous with effluent releases from former TA-45 and with the pre-1965 sand deposits in P-4 West (Figure 3.3-1). Similarly, the highest plutonium concentration found in reach P-2 is from a subsurface layer in the c2 unit of P-2 West that may date to this period, whereas most other c2 sediment in P-2 West has much lower concentrations of plutonium and probably postdate the sewer line that was emplaced in the early 1960s (Figures 2.3-8 and 3.3-4). The highest plutonium concentration in reach P-3, from an overbank sediment sample from the surface of the c4 unit in P-3 West near the location of the main channel in 1954 (Figure 2.3-14), is also inferred to date from the early post-1942 period. Possible trends of decreasing plutonium concentration over time in the c2 overbank sediments of reach P-2 are suggested by vertical changes in plutonium concentration, with near surface samples having the lowest concentrations (Figures 3.3-4 and 3.3-5). Decreasing concentrations in overbank facies sediment over time are also suggested by differences between samples from P-4 that are probably dominated by sediment deposited during the 1970s and samples from reach P-3 that are probably dominated by younger sediments from the 1980s and 1990s (an average of approximately 6.0 pCi/g in P-4 and 1.5 pCi/g in P-3). Data from active channel sediments at the environmental surveillance sampling station at Acid Weir also suggest a decreasing trend of plutonium concentration over time since 1970 (Figure 3.3-3), whereas data from other surveillance stations in reaches P-2 West and P-3 suggest relatively low levels being maintained during the past 20 years in active channel sediments (Figures 3.3-7 and 3.3-12).

4.2.3 Spatial Trends

Two key spatial trends in contamination of Pueblo Canyon sediments are part of the preliminary conceptual model from the work plan (LANL 1995, 50290) based on the results of prior investigations (e.g., LANL 1981, 6059; Graf 1995, 48851; Graf 1996, 55537). First, plutonium concentrations tend to decrease downstream from the source at former TA-45 and second, plutonium inventory increases downstream from Acid Canyon and is highest in the eastern part of Pueblo Canyon. Although this investigation has in part confirmed both of these spatial trends, the data presented in this report also show that these trends are highly irregular and are strongly influenced by the time-dependent trends that were discussed in Section 4.2.2 and by variations in the timing of sediment deposition and incision between reaches.

4.2.3.1 Spatial Trends in Plutonium Concentration

Estimated geographic variations in average plutonium concentration in channel facies and overbank facies sediment in the Pueblo Canyon reaches are shown in Figure 4.2-1. These average concentrations are derived from the average values presented in Tables 3.3-3, 3.3-6, 3.3-9, and 3.3-12 and are weighted by the estimated volume of sediment in each geomorphic unit. This figure shows a downstream decrease in average plutonium concentration in each facies between reaches P-1 and P-3 but an increase in reach P-4. The same general pattern is seen in plots of all data collected from Pueblo Canyon in this investigation (Figure 4.2-2). The apparently anomalous increase in plutonium concentration in reach P-4 can be explained by the occurrence of exceptionally large deposits of sediment dating to the early post-1942 period in this part of Pueblo Canyon, contrasting with other reaches where much smaller percentages of the total sediment volume are represented by this time period, as shown schematically in Figure 4.1-2. Thus, although plutonium concentrations in sediment of a given age can be expected to decrease downstream, maximum and average concentrations do not always show such a trend because of complex depositional histories.

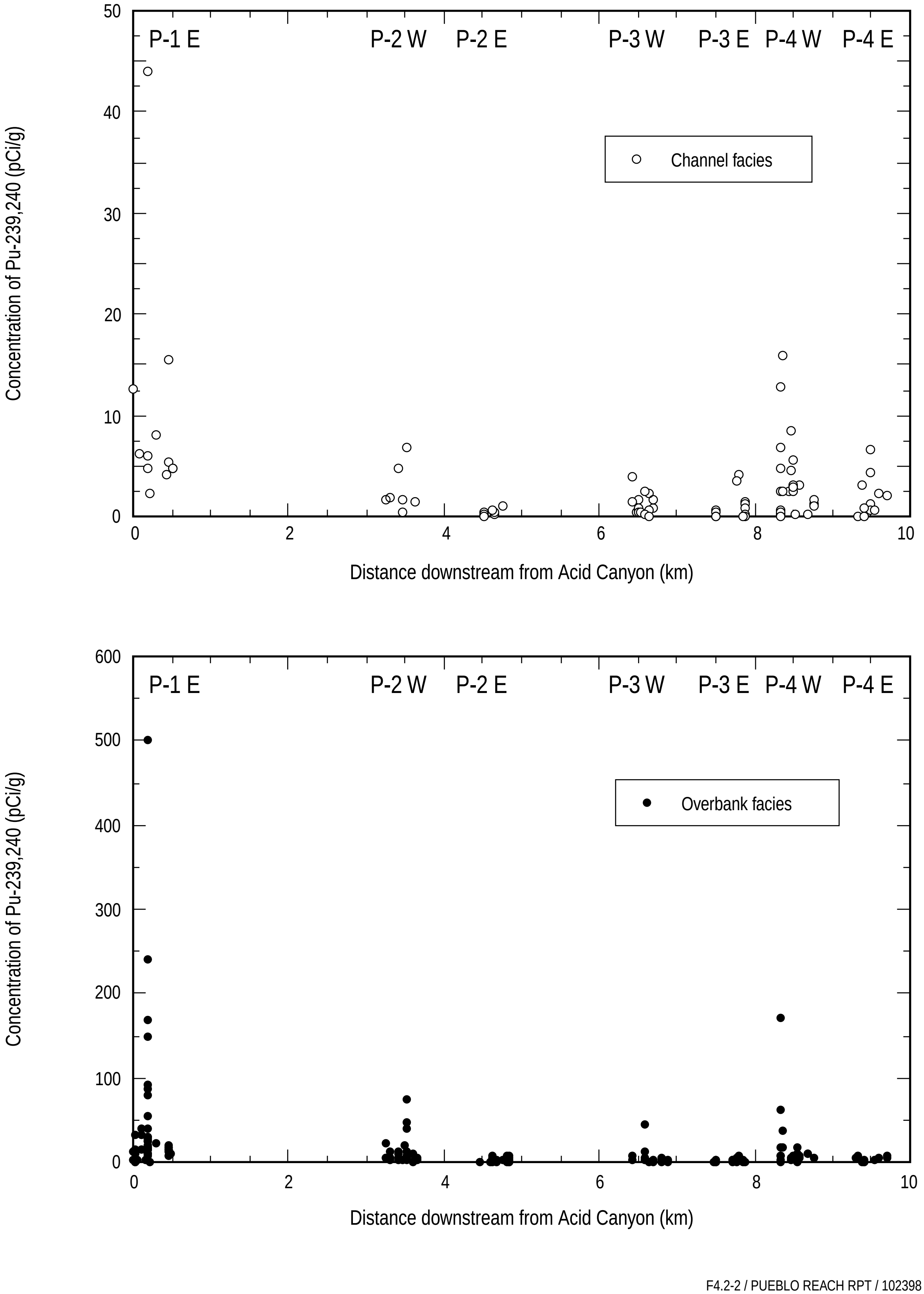


Figure 4.2-2. Plutonium concentrations in Pueblo Canyon sediment samples.

It is also notable that data from both this investigation and prior investigations show a slight increase in the plutonium concentration in post-1965 channel facies sediment between reaches P-3 and P-4, although concentrations tend to decrease downstream from Acid Canyon to P-3 (Figure 4.2-3). This increase in the lowest part of Pueblo Canyon is believed to result from the extensive incision occurring in P-4 during the last several decades, as shown schematically in Figure 4.2-4, which has resulted in remobilization of older post-1942 sediment with higher concentrations of plutonium than occur at the surface in P-3. The lowest plutonium concentrations in active channel sediments at present occur in reach P-2 East (Figure 4.2-3), which may result from a relatively large part of these sediments being derived from Kwage Canyon.

4.2.3.2 Spatial Trends in Plutonium Inventory

The results of this investigation support previous studies (LANL 1981, 6059; Graf 1995, 48851; Graf 1996, 55537) by showing that the largest part of the plutonium inventory in Pueblo Canyon occurs in the easternmost part of the canyon, including reach P-4 (Figure 4.2-5). This high inventory is related to the presence of both a much larger volume of post-1942 sediment in P-4 as compared with other reaches (Figure 4.2-6) and to relatively high plutonium concentrations associated with large percentages of early post-1942 sediment, particularly in P-4 West (Figure 4.2-1). The net effect of floods since 1942 has been to transport a large percentage of the plutonium many kilometers from the source and to preferentially deposit it in lower Pueblo Canyon, where it has been stored for decades. Most of the plutonium in downstream reaches (P-4) is contained within the large volumes of relatively coarse-grained sediment deposits, whereas most of the plutonium in upstream reaches (P-1 East, P-2 West) is contained within relatively fine-grained deposits (Figure 4.2-5).

One revision to the preliminary conceptual model concerns the percentage of plutonium stored within sediments relatively close to the source. Based on data on plutonium concentrations from prior investigations and geomorphic mapping, Graf (Graf 1995, 48851; Graf 1996, 55537) had estimated that only approximately 6% of the total plutonium in Pueblo Canyon was stored west of Test Wells 2 and 2A or west of reach P-2 West. In contrast, the results of this investigation (Table 4.2-1) suggest that approximately 25% of the plutonium is stored here. The higher percentage in this investigation is due largely to higher estimates of average plutonium concentration in the overbank facies sediments of reaches P-1 East and P-2 West in this investigation (20.6 and 11.2 pCi/g, respectively; Table 4.2-1) than in previous overbank analyses used by Graf (averages of 3.5 and 6.4 pCi/g for these parts of Pueblo Canyon).

4.3 Fate and Transport of Contaminants

The primary COPC in Pueblo Canyon sediments, plutonium-239, has a half-life of 24,000 years and will not experience significant decreases in concentration because of radioactive decay over time scales that are relevant for evaluating risk. Under natural conditions, future changes in contaminant levels from those documented in this investigation will thus be the result of processes that transport or mix sediment, involving both sediment containing variable levels of contamination and sediment that is presently uncontaminated. The following sections discuss important transport processes occurring in Pueblo Canyon and the likely effects of these processes on future levels of contamination.

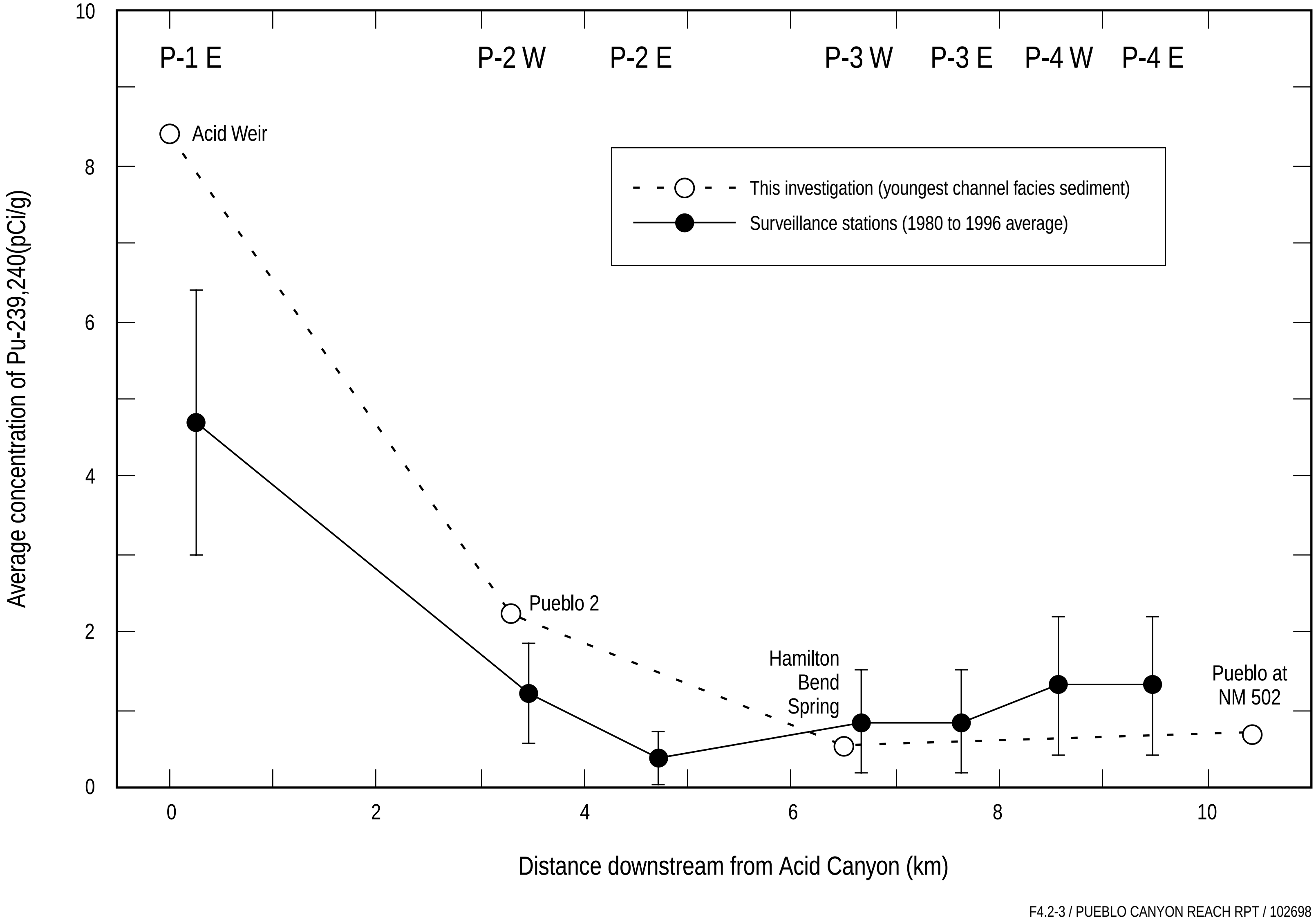


Figure 4.2-3. Plutonium concentrations in young channel facies sediment in Pueblo Canyon.

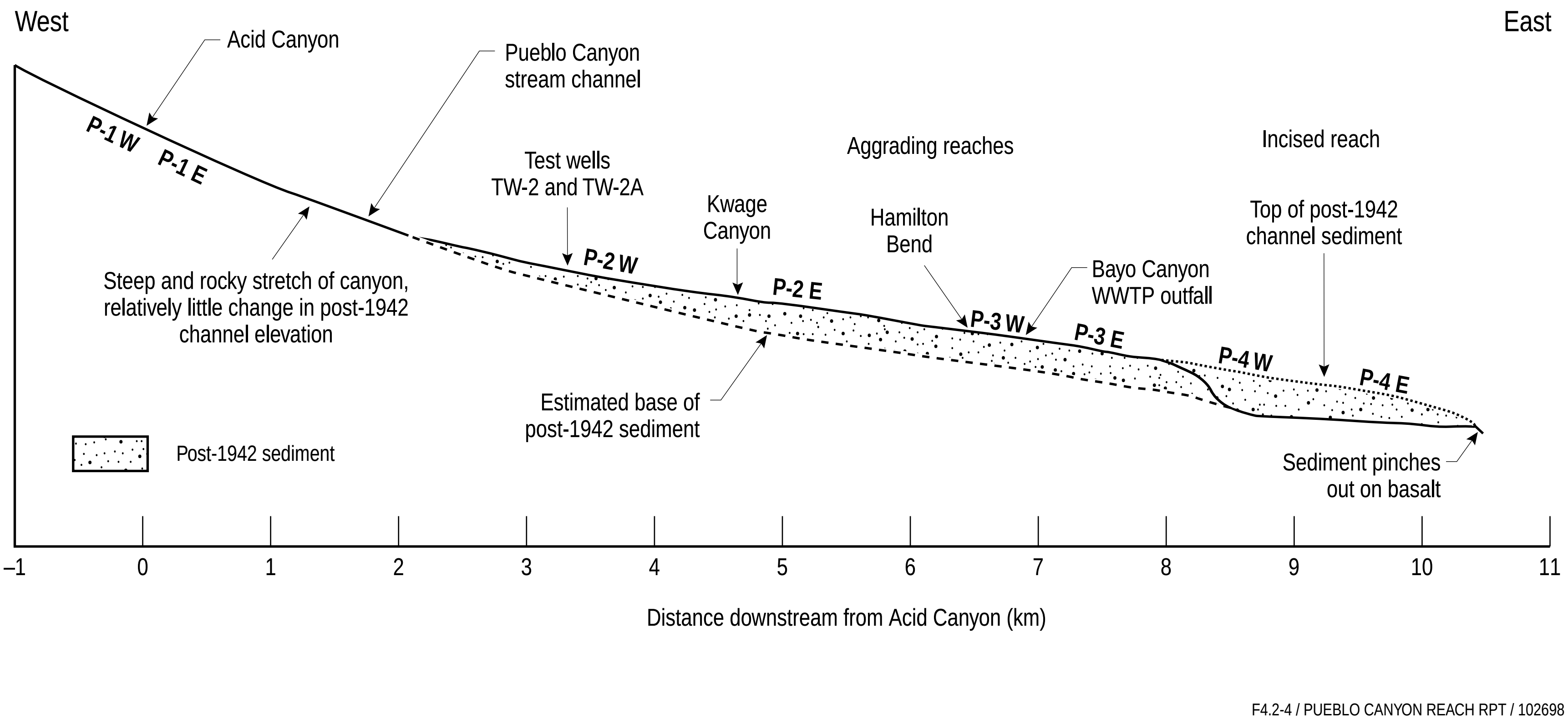
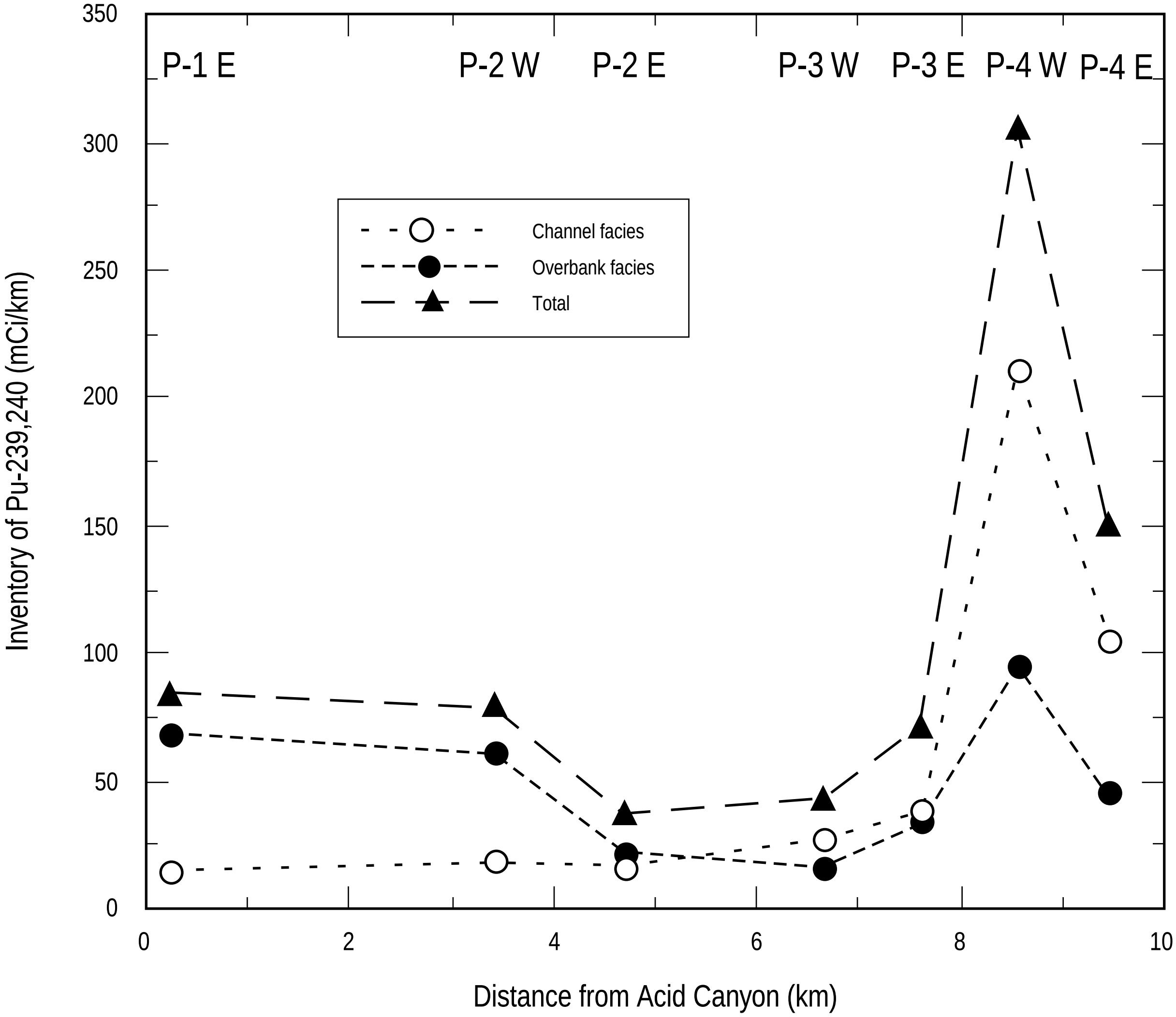


Figure 4.2-4. Schematic longitudinal profile of Pueblo Canyon showing variations in the thickness of post-1942 channel sediment and areas of aggradation and incision.



F4.2-5 / PUEBLO CANYON REACH RPT / 102698

Figure 4.2-5. Variations in estimated inventory of plutonium-239,240 in post-1942 channel facies and overbank facies sediment in Pueblo Canyon.

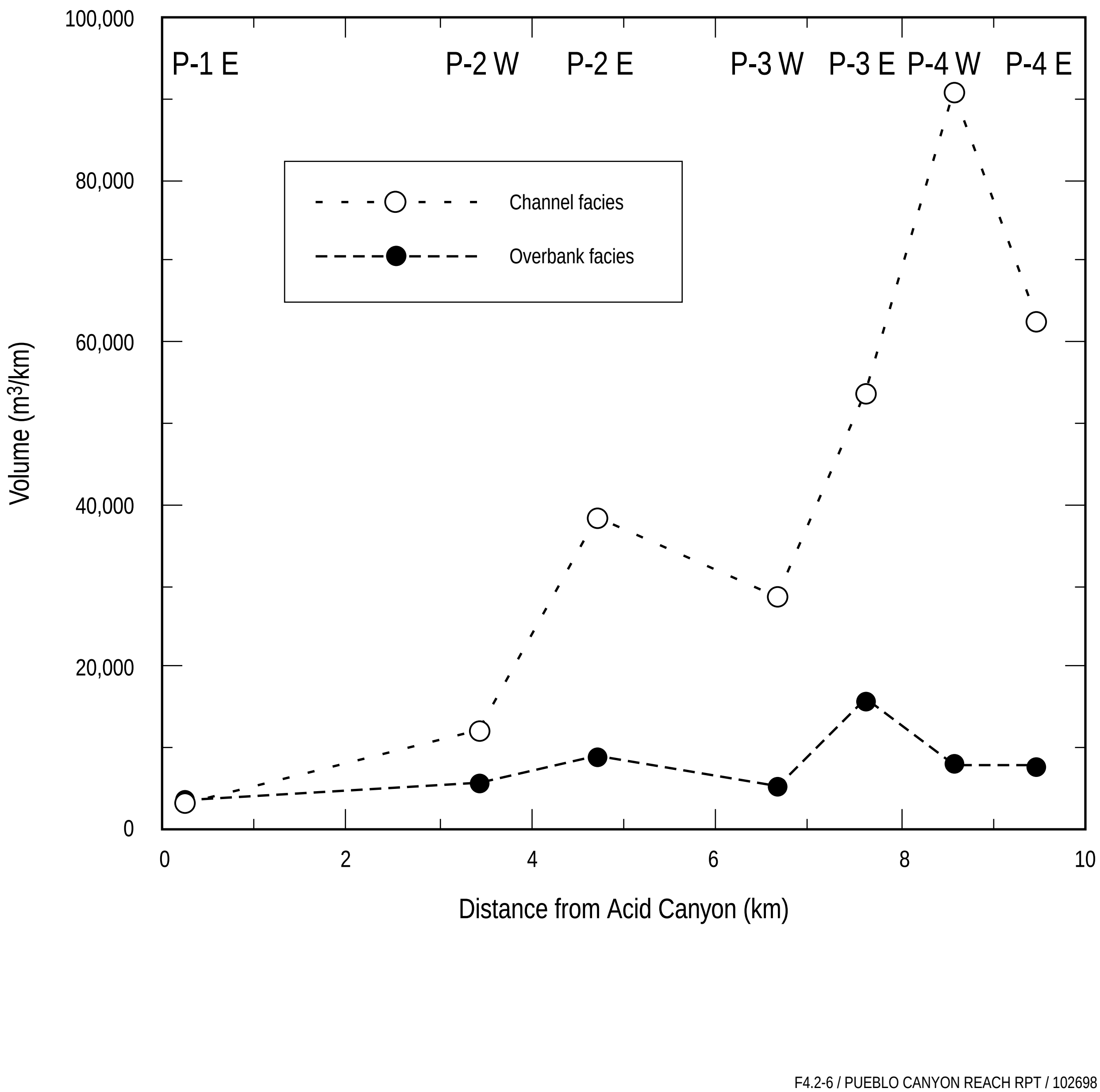


Figure 4.2-6. Estimated volume of post-1942 sediments in Pueblo Canyon.

4.3.1 Original Effluent Releases and Resultant Contaminant Distribution

Plutonium and other contaminants in the Pueblo Canyon watershed were originally supplied largely by effluent releases from TA-45 into Acid Canyon. This radioactive effluent flowed down the main channel of Acid Canyon into Pueblo Canyon and infiltrated into the stream beds in both canyons. Because of the nature of Laboratory operations, the radionuclides may have been largely in solution in the original effluent, but because of their geochemical characteristics they would have tended to adsorb onto sediment particles or organic colloids (e.g., Langmuir 1997, 56037). Plutonium associated with organic colloids would have the greatest mobility, but because of the low organic matter content typical for sediments in the stream beds it is expected that only a small percentage of the plutonium became bound to organic colloids. (Note that TA-45 effluent releases overlapped with releases from the Pueblo Canyon WWTP from 1951 to 1964, and the latter may have increased the nutrient levels and organic matter content in the active channel relative to pre-Laboratory conditions.) The remainder of the plutonium preferentially adsorbed to the finer-grained sediments because of their greater surface area and, in the case of clay minerals, their high cation exchange capacity. However, the data obtained in this investigation and in previous investigations indicate that large percentages of the plutonium in Pueblo Canyon are associated with relatively coarse-grained sediments, consistent with the fact that the stream beds are dominated by coarse sand and gravel. The exact association of the radionuclides and specific particle size fractions has not been determined, and much of the plutonium in coarse-grained sediments could be associated with either the fine fraction of these deposits or more geochemically favorable coatings on the coarse fraction such as clay or iron oxides. Regardless of the specific geochemical location of the radionuclides, the effluent releases incrementally built up inventories within the active channel sediments, which were very susceptible to remobilization during floods.

4.3.2 Effects of Floods

Floods constitute the primary transport process for sediment and associated contaminants in Pueblo Canyon, and the combined effects of numerous floods during the past 55 years have largely controlled the horizontal and vertical extent of contaminated sediments and variations in contaminant concentration. Indirectly, floods have therefore strongly affected any human and ecological risk that may be associated with contaminated sediments. Importantly, the present variations in plutonium concentration in Pueblo Canyon sediments, combined with documentation of channel changes since 1942, provide a geomorphic record of the past effects of floods and a means to forecast likely future changes in contamination.

Floods transport sediment from upstream to downstream parts of a watershed and in the process both redistribute mass and change the concentrations of contaminants in resultant sediment deposits. The sediment transported in each flood is derived from a variety of sources that include the bed and banks of the main stream channel and tributary drainage basins, the latter including major tributaries such as Acid and Kwage Canyons as well as rills and other small channels on canyon walls.

Much of the plutonium transported by floods during the time of the original effluent releases may have been derived from scour of the active stream bed in both Acid and Pueblo Canyons, although the plutonium would have become depleted from this source following termination of the effluent releases and other sediment storage sites such as abandoned channels, and floodplains would have become progressively more important as sources for plutonium. Contaminants in abandoned channels and floodplains will be mostly remobilized by lateral bank erosion. Thus the location and rates of bank erosion will have a major influence on contaminant concentrations, and concentrations could vary significantly between floods. Preferential erosion of post-1942 deposits in a flood would result in higher plutonium concentrations than preferential erosion of pre-1943 deposits. In addition, the relative amounts of sediment supplied by bank erosion versus that supplied from tributary drainages in individual floods will affect plutonium concentrations. For example, at present Kwage Canyon appears to be a major sediment source in the Pueblo Canyon watershed, and plutonium concentrations are relatively low in reaches P-2 East and P-3 immediately downstream. Since the termination of effluent releases from TA-45 in 1964, the net effect of the mixing of sediment from a variety of sources has been to reduce contaminant concentrations transported by floods from those before 1965 (Section 4.2.2), and future decreases in contaminant concentration can be expected.

Sediments are sorted during floods, and contaminants associated with different size classes of sediment will be transported different distances and deposited in different locations. Coarse sand grains are largely transported by rolling or saltation (bouncing) along the stream bed and will tend to be transported relatively short distances in each flood and to be deposited on the stream bed, although large floods can also temporarily suspend coarse sand grains and deposit them in overbank deposits near the stream channel. The finest particles (i.e., clay- and silt-sized particles) are easily suspended in floods and can be transported the longest distances in individual floods. Silt and clay particles carried in suspension can be deposited in the active channel by water that infiltrates the stream bed, deposited on adjacent surfaces inundated by overbank floodwaters, or carried directly into downstream drainages such as Los Alamos Canyon or the Rio Grande. Plutonium concentrations in sediment deposited by individual floods may generally be highest in those locations where silt and clay percentages are the highest, although it is also possible that sediments with abundant silt- and clay-sized particles will have relatively low concentrations of plutonium if these particles are mostly derived from noncontaminated drainages (e.g., Kwage Canyon).

Average sediment residence times, or the average time between floods that remobilize specific sediment particles, will vary among sediment deposited in different geomorphic locations. Residence times for sediment in active channels will be relatively short, and sediment in these areas can be mobilized easily in floods. In contrast, residence times for sediment deposited on floodplains can exceed 100 years, based on the age of trees growing on these surfaces. Sediment in many of the abandoned channel units along the active channel of Pueblo Canyon have estimated residence times of 30 to 50 years or less, based on plutonium concentrations and geomorphic and sedimentologic characteristics. However, sediment in abandoned channel units in areas affected by major channel changes probably have residence times that exceed 50 years (such as the c5 unit in P-4 West that probably dates to the early 1950s).

Significant changes in the elevation of the stream bed along most of Pueblo Canyon have occurred during floods since 1942 and have had a major influence on the distribution of plutonium. At different times, different reaches have either aggraded (raising of the stream bed by sediment deposition) or degraded (lowering of the stream bed by channel incision). The largest part of the present plutonium inventory occurs in P-4 West (Figure 4.2-5), an area that was aggrading during the time of the original effluent releases, resulting in relatively large volumes of early post-1942 sediment. At present, reach P-4 is incising but reaches P-2 East and P-3 are aggrading (Figure 4.2-4), and most of the sediment in P-2 East and P-3 is relatively young and possesses lower concentrations of plutonium than the older P-4 deposits. This complex behavior of the stream channel is believed to be due to large fluctuations in the rate that sediment is supplied to the main Pueblo Canyon channel (Reneau et al. 1996, 57642), a process that has been documented in other semiarid watersheds (Germanoski and Harvey 1993, 58670). The source for sediment that may have driven the early post-1942 aggradational period in P-4 is not known, but the most important sediment source at present appears to be within Kwage Canyon (in particular a steep eroding colluvial slope located 0.6 km upstream from the confluence with Pueblo Canyon).

4.3.3 Effects of Bioturbation

A variety of fauna, particularly burrowing mammals, can be very effective at mixing soils and thus locally changing concentrations of contaminants. Such biological mixing processes are collectively known as bioturbation, a term that also includes mixing by plants, including disruption caused by toppling trees.

Evidence of burrowing mammals is widespread within areas of post-1942 sediment in Pueblo Canyon, and related sediment mixing affects contaminant levels over a range of time frames and spatial scales. Bioturbation can locally increase contaminant levels in soils by transporting sediment that is contaminated into subsurface layers or onto surfaces that are uncontaminated or that contain contaminants at lower levels. However, bioturbation will also locally decrease contaminant levels by mixing uncontaminated soils, such as those present in pre-1943 deposits, into post-1942 plutonium-bearing sediment deposits. In general, the net effect over time is probably to reduce the vertical stratification in contamination that resulted from original deposition of sediment layers with varying plutonium levels, producing more homogeneous contaminant concentrations in sediments. Where bioturbation is restricted to the depth of post-1942 sediment packages, resulting average contaminant levels for such sediment packages should be similar to those estimated in Section 3. Alternatively, where bioturbation extends to greater depths, the effect of such mixing will be to reduce average plutonium concentrations while increasing the volume of plutonium-bearing soils.

An additional effect of bioturbation is to bring fresh loose material to the surface. Such loose material is more susceptible to redistribution by rainsplash, wind, or aboveground animals than adjacent areas that may be well vegetated or otherwise resistant to erosion. Thus bioturbation contributes to other transport pathways and exposure pathways. Rainsplash of this loose material causes only very local redistribution, but it is important in the context of transferring contaminated material onto plant surfaces where it can be ingested. Wind and animals can potentially transport contaminated material onto uncontaminated geomorphic units, and of these processes wind is likely more significant.

4.3.4 Transport by Wind

Wind has likely provided a mechanism for at least local redistribution of contaminants within Pueblo Canyon, in addition to its role in exposure pathways included in the risk assessments in Section 5.1. Wind transport may help account for the observation that samples collected from geomorphic surfaces that have probably not been directly inundated by post-1942 floods often have concentrations of plutonium somewhat above background values although well below those found within nearby post-1942 sediments. Recently deposited, unvegetated, fine-grained overbank sediment may provide an important source for wind-transported sediment with contaminant levels above background, as has been documented in other regions (e.g., Lechler et al. 1997, 58475). Areas disturbed by burrowing mammals may provide an additional source, as discussed in Section 4.3.3. However, it is important to note that eolian sediment derived from post-1942 deposits will also be mixed with material eroded from uncontaminated areas, resulting in dilution. Sources of eolian sediment during or between wind storms may be extremely variable, and no attempt has been made to evaluate the relative contributions of contaminated and uncontaminated areas in providing eolian sediment in Pueblo Canyon.

4.3.5 Transport by Alluvial Groundwater

Alluvial groundwater, probably largely derived from effluent releases in the Pueblo Canyon watershed, has caused at least partial redistribution of plutonium within post-1942 sediments and into pre-1943 sediment deposits (Section 4.1.2). This transport may include a combination of plutonium associated with organic colloids, which could be transported relatively easily within alluvial groundwater systems, and plutonium adsorbed onto clay particles. Plutonium concentrations in the deep sediment bodies that resulted from such subsurface transport are relatively low as compared with near-surface deposits. In addition, little transport of plutonium from the alluvium into underlying substrates is indicated by samples at two locations in reaches P-2 East and P-3 East (Figures 3.3-6 and 3.3-11). Subsurface transport is expected to be most active downstream from treatment plants, which provide large volumes of water and produce persistent alluvial groundwater bodies, such as has occurred downstream from the Bayo Canyon WWTP since 1963 (reaches P-3 East and P-4). Effluent releases from TA-45 (1944 to 1964), the Pueblo Canyon WWTP (1951 to 1991), and the Central WWTP (1947 to 1966) probably caused similar subsurface transport in reach P-1 and downstream reaches. Another effect of discharges from the treatment plants would have been to increase nutrient loads along the active stream channels, and hence potentially increase concentrations of organic colloids that could aid transport of plutonium and other COPCs, although the importance of such transport in Pueblo Canyon is unknown.

4.3.6 Future Remobilization and Transport of Contaminants

A general evaluation of the effects of future remobilization and transport of contaminated sediment by natural processes can be made based on the results of this investigation, particularly using data on important transport processes and resultant changes in plutonium concentration and distribution since 1942, as discussed in previous sections. A time frame of approximately 50 years is chosen for this evaluation because available data are best suited for understanding sediment transport processes in Pueblo Canyon over this temporal scale.

Future floods will continue to redistribute plutonium within Pueblo Canyon and to transport some of this plutonium into Los Alamos Canyon. This redistribution will reduce the plutonium inventory in some reaches and perhaps increase the inventory in some downstream areas. The plutonium most susceptible to remobilization is that part of the total inventory stored within the presently active channel (c1) and in geomorphic units adjacent to the active channel, such as the c2 units. In these areas sediment residence times are generally less than 55 years, and remobilization is likely during the next 50 years. However, large areas of abandoned channels and floodplains are removed from the active channel, and average sediment residence times in many of these areas probably exceed 50 years.

Preliminary evaluations of the susceptibility of post-1942 sediment deposits in the Pueblo Canyon reaches to remobilization (Tables 3.3-3, 3.3-6, 3.3-9, and 3.3-12) suggest that roughly 60% of the plutonium could remain in its present location for 50 years or more (Table 4.2-1, Figure 4.3-1). In addition, some undefined part of the plutonium that is remobilized will be redeposited in stable geomorphic settings in downstream reaches and remain within Pueblo Canyon during this period. Therefore, it is expected that less than 40% of the plutonium presently in Pueblo Canyon will be transported into Los Alamos Canyon during the next 50 years. Importantly, less than 20% of the large plutonium inventory in reach P-4 close to the Laboratory boundary is considered susceptible to remobilization during the next 50 years (Figure 4.3-1).

Although there are many poorly defined uncertainties associated with these inventory calculations, the estimates of the percentage susceptible to remobilization are intended to be conservative and to overestimate the amount of contaminated sediment that will be remobilized. For example, the above estimates assume that a period of channel incision similar to that presently occurring in reach P-4 will occur in the upstream reaches that are presently aggrading (P-2 East and P-3), completely remobilizing sediment below the surfaces of the c1 and c2 units in these reaches. However, it is also possible that these reaches will continue aggrading or remain unincised, reducing the transport through these reaches, or that a period of incision would involve only part of the units along the active channel and that the rest would remain stable for long periods, similar to the c5 unit in P-4 West that has been largely stable since the early 1950s. In addition, major channel changes could occur that divert the channel away from the primary post-1942 sediment deposits and into floodplain settings with only thin layers of post-1942 sediment.

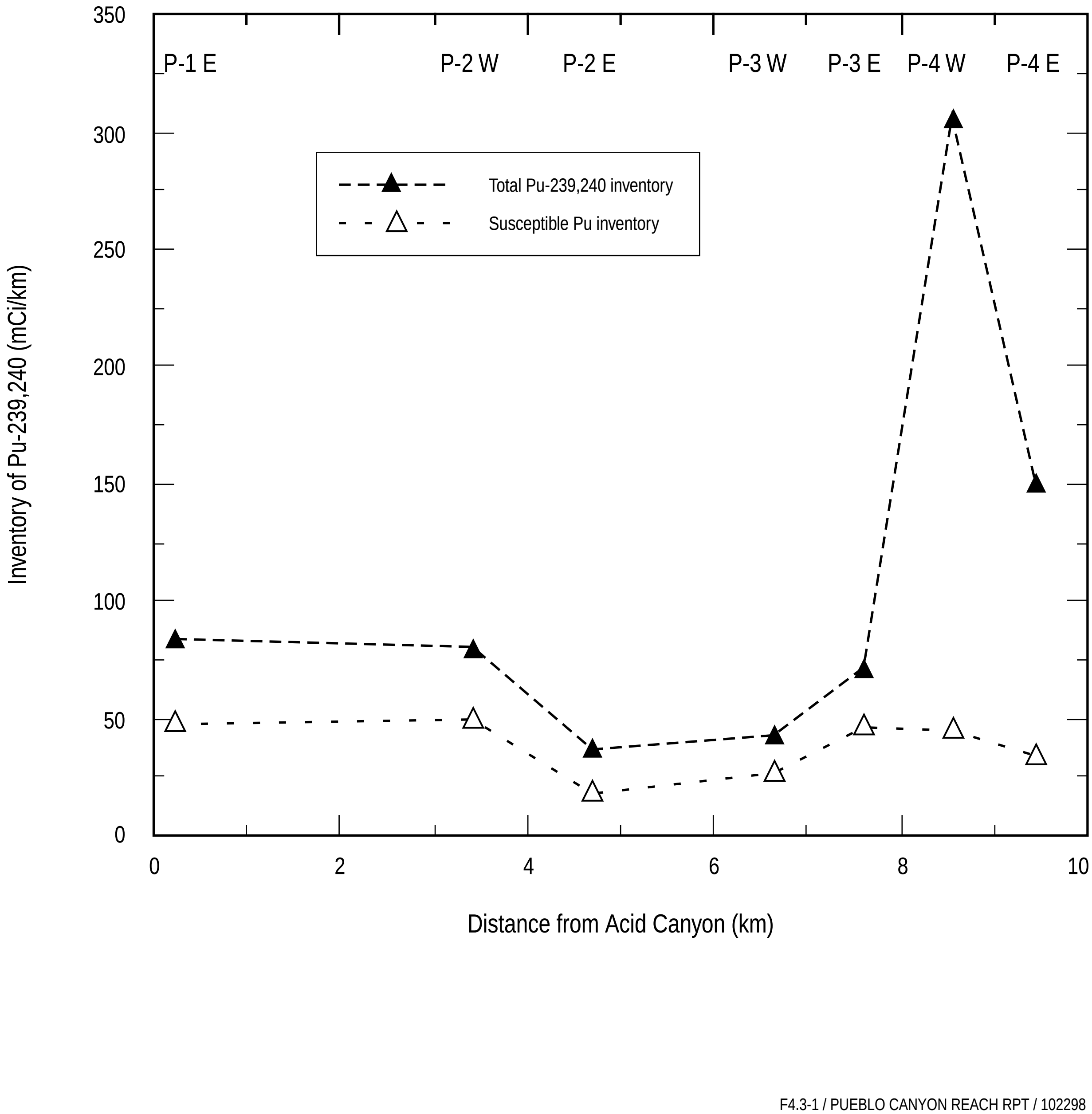


Figure 4.3-1. Variations in the total estimated plutonium-239,240 inventory and the fraction of the inventory considered to be susceptible to remobilization during the next 50 years in Pueblo Canyon.

The plutonium in Pueblo Canyon most susceptible to transport into Los Alamos Canyon is located in reach P-4 and between P-4 and state road NM 502 and occurs within the c1 unit and other post-1942 sediment deposits close to the active channel. The slight increase in plutonium concentration in young channel facies sediment that occurs between P-3 West and P-4 (Figure 4.2-3) is probably the result of such remobilization of plutonium from the bed and banks, and the relatively low variation in plutonium concentration in the channel sediments of P-4 during the past 30 years (Figure 3.3-18) suggests that current plutonium concentrations in the active stream channel may be maintained for decades.

A likely worst-case scenario for the remobilization of plutonium in Pueblo Canyon sediments and their transport into Los Alamos Canyon might involve one or more extreme high-magnitude floods that cause widespread bank erosion in reaches such as P-1 and P-2 West and trigger a period of channel incision in reaches that are currently aggrading (P-2 East and P-3). Although relatively little plutonium is stored within P-2 East and P-3, creation of an incised channel would probably allow more effective transport of sediment derived from upstream reaches than at present because runoff would be confined between higher banks and would be deeper. Under these conditions significant redistribution of plutonium might occur quickly. Such high-magnitude floods would likely cause substantial erosion of pre-1943 sediments that contain virtually no plutonium as well as provide additional clean sediment from Kwage Canyon and other tributary drainages, helping to dilute the plutonium supplied from upstream reaches, although the amount of dilution is difficult to predict.

5.0 SITE ASSESSMENTS

5.1 Preliminary Human Health Risk Assessment

5.1.1 Scope and Objectives

The purpose of this section is to evaluate the data on contaminants in Pueblo Canyon sediments relative to potential human health effects. The emphasis of this analysis is to determine whether a site management decision to mitigate potential human health risks is warranted at present. This analysis uses present-day contaminant concentrations and reasonable present-day exposure scenarios and does not assess the possible effects of future contaminant redistribution or potential future land uses.

The assessment in this interim report is focused on risks resulting from direct exposures to contaminants in sediments via ingestion, inhalation and dermal contact, and indirect exposures through consuming foodstuffs that have grown on contaminated sediments or meat from animals that have consumed plants in these areas. Data are not presently available to perform assessments that include water pathways, but water pathways will be included in more comprehensive risk assessments in one or more future reports on Pueblo Canyon.

5.1.2 Comparison with Core Document Risk Approach

Chapter 6 of the *Core Document for Canyons Investigations* (“the core document”) (LANL 1997, 55622) proposes risk assessments that include sediments, surface water, groundwater, and air particulates. These media were proposed to be evaluated in nine exposure scenarios over three land uses. The continued Laboratory land use includes a construction worker scenario and an on-site worker scenario. The recreational land use has both a trail user scenario and a camper scenario. The American Indian land use consists of scenarios for residential use, ranching, hunting, traditional uses, and use of the Rio Grande and Cochiti Lake.

The assessment in this report uses scenarios for a trail user, a resource user (incorporating aspects of a ranching or hunting scenario), and a construction worker. These scenarios are considered to be inclusive of realistic present-day potential exposure activities in Pueblo Canyon. The basis of primary and secondary exposures are the concentrations of contaminants in sediments. The other scenarios proposed in the core document are not currently active in Pueblo Canyon and will not be evaluated in the this interim report.

Development of an American Indian land use scenario is proposed in the core document. The intent of that land use scenario is to uniquely define the parameters of exposure pathways that reflect the activities of the local American Indian populations. However, the American Indian scenario is not sufficiently developed to be applied in this report. An approximation of the American Indian scenario could be achieved by combining a residential scenario with the resource user scenario, although a residential scenario is not included in this report because it is not a reasonable present-day scenario for Pueblo Canyon.

Each of the exposure scenarios evaluated in this report is applied over the entire area of each reach. This means that an average contaminant concentration is calculated for each reach and is used for the potential risk estimate as described in Section 5.1.4 and Perona et al. (1998, 62049). The method of averaging is addressed in Section 5.1.6. This method is in contrast to the approach proposed in the core document, which involves using different size exposure areas for different scenarios. The trail use, resource use, and construction activity would likely occur along a whole reach. Therefore, it is reasonable to use the whole reach averages as a means for estimating exposure. Scale issues related to the other scenarios in the core document will be addressed when those scenarios are evaluated in future assessments.

Human health risks for this report are estimated by comparing the maximum values, and for key radionuclides the average values, for each of the chemicals of potential concern (COPCs) with preliminary remediation goal (PRG) values. The PRGs are generated by using the parameters associated with each of the scenarios, as described in Section 5.1.4, and computing the contaminant concentration that would result in a threshold risk. This is consistent with the Environmental Protection Agency (EPA) manual *Risk Assessment Guidance for Superfund: Volume I—Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)* (RAGS) (EPA 1991, 58234). For example, the EPA has provided guidance that 15 mrem/yr is a protective dose limit for radionuclides (EPA 1997, 58693). This is more conservative than the dose limit of 25 mrem/yr proposed by the Nuclear Regulatory Commission for unrestricted use of a site (10 CFR 20) and the limit of 100 mrem/yr in Department of Energy (DOE) Order 5400.5, "Radiation Protection of the Public and the Environment."

An example of the use of PRGs in this report follows. Given the description of the trail user scenario in Section 5.1.4, the concentration of plutonium-239 in the sediments that results in an exposure of 15 mrem/yr is 440 pCi/g, which constitutes the PRG, The measured maximum value for plutonium-239,240 in Pueblo Canyon is 500 pCi/g. Therefore, the PRG is 88% of the measured maximum value. Based upon this initial screening assessment using maximum sample results, plutonium-239,240 is investigated further in Section 5.1.6 using average values for all geomorphic units in each reach. (Note that toxicity values for plutonium-239 are used for the plutonium-239,240 data obtained in this investigation because high precision analyses have indicated that only low percentages of plutonium-240 are present in sediments at the Laboratory [Gallaher et al. 1997, 59165].)

The PRG concentrations for chemical carcinogens are based on a potential risk of 10^{-6}. The noncarcinogen PRGs are based on a hazard quotient (HQ) of 1. The maximum contaminant values are compared with the PRGs to determine which contaminants are likely risk drivers. The contaminant averages are used for estimating exposures supporting decisions regarding risk management or risk mitigation for the key radionuclide COPCs. The concentration averages are often referenced to sediment packages, which are combinations of geomorphic units and sediment facies presented in Tables 3.3-2, 3.3-5, and 3.3-8.

Approaching risk characterization in this manner supports site management decisions about present-day potential risks and the possible need for remediation of sediments. This is a deterministic approach that uses the contaminant concentration data to make individual contaminant assessments. Where contaminants are collocated, the percent PRGs can be summed to estimate the integrated potential exposures. Performing stochastic uncertainty and sensitivity analyses is deferred to later reports when sufficient data are available to evaluate the surface water and groundwater exposure pathways.

5.1.3 Selection of COPCs

Section 3.1 provides an analysis of the contaminant data from Pueblo Canyon sediment samples and a selection of the COPCs that warrant further consideration in site management decisions. There are 6 radionuclides, 8 inorganic chemicals, and 29 organic chemicals recommended for further evaluation (Table 5.1-1). A primary focus of the investigation in Pueblo Canyon was to determine the concentrations and distribution of plutonium-239,240, which was selected as a key contaminant based on the results of previous investigations and the full-suite analyses conducted in this investigation. Additional contaminant analyses were obtained to assess the presence of additional COPCs and to evaluate possible collocation of other contaminants with plutonium.

TABLE 5.1-1

PUEBLO CANYON MAXIMUM CONTAMINANT VALUES AND EXPOSURE SCENARIO PRGs[a]

COPC	Pueblo Maximum Value[b]	Trail User PRG	Resource User PRG	Construction Worker PRG
Organic Chemicals				
Aroclor-1254	0.24	16	16	2.6
Aroclor-1260	0.12	.95	0.95	4.5
Aldrin	0.0021	0.074	0.074	0.42
δ-BHC	0.0020	0.20	0.20	1.1
α-Chlordane	0.0050	3.6	3.6	20
γ-Chlordane	0.0021	3.6	3.6	20
4,4'-DDT	0.0060	3.7	3.7	21
Acenaphthene	0.22	32000	32000	61000
Acenaphthylene	0.44	32000	32000	61000
Anthracene	0.37	16000	16000	30000
Benz(a)anthracene	1.0	1.7	1.7	9.7
Benzo(a)pyrene	1.7	**0.17**[c]	**0.17**	**0.97**
Benzo(b)fluoranthene	2.5	**1.7**	**1.7**	9.7
Benzo(g,h,i)perylene	0.86	N.A.[d]	N.A.	N.A.
Benzo(k)fluoranthene	0.95	17.00	17	97
Benzoic Acid	0.75	1500000	1500000	370000
Bis(2-ethylhexyl)phthalate	2.8	90	90	500
Carbazole	0.18	63	63	350
Chrysene	1.2	170	170	970
Di-n-octylphthalate	0.094	11000	11000	2000
Dibenz(a,h)anthracene	0.28	**0.17**	**0.17**	0.97
Dibenzofuran	0.18	2200	2200	400
Fluoranthene	1.90	22000	22000	4000
Fluorene	0.29	22000	22000	4000
Indeno(1,2,3-cd)pyrene	0.88	1.7	1.7	9.7
2-Methylnaphthalene	0.17	2200	2200	400
Naphthalene	0.37	2200	2200	400
Phenanthrene	1.5	16000	16000	3000
Pyrene	2.2	16000	16000	3000
Inorganic Chemicals				
Antimony	ND[e][4.9][f]	890.00	48	77
Cadmium	0.92	2200	6.6	180
Copper	32	87000	250	7700
Lead	77	400	400	400
Mercury	0.65	660	**0.22**	57
Selenium	0.98	11000	6.7	960
Silver	1.7	11000	61	960
Zinc	110	56000	330	57000
Radionuclides				
Americium-241	11	420	160	23
Cesium-137	1.5	510	71	19
Plutonium-238	2.1	480	170	26
Plutonium-239,240[g]	500	**440**	**150**	**24**
Strontium-90	1.4	11000	12	610
Tritium	1.2	2300000	3100	1100000

a. Values for organic and inorganic chemicals are expressed in mg/kg; values for radionuclides are expressed in pCi/g.
b. Maximum values are rounded to two significant figures.
c. Boldface values indicate PRGs that are exceeded by the maximum result.
d. N.A. = not available
e. ND = not detected
f. Maximum nondetected value
g. PRGs for plutonium-239,240 are calculated using the toxicity value for plutonium-239.

A screening assessment of the other COPCs using maximum values and PRGs is presented in Figure 5.1-1. The lines of equality in these plots separate the plot regions into two areas. Points that plot to the right of the lines of equality are maximum COPC values that are less than their PRGs. Points that plot to the left of the lines of equality exceed PRGs and are evaluated further. In addition to plutonium-239-240, the COPCs, that exceed their PRGs are benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene for the trail user scenario; mercury, benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene for the resource user scenario; and benzo(a)pyrene for the construction worker scenario. Plutonium-239,240 is the only COPC that exceeds its PRG for the construction worker scenario. Plutonium-239,240 is a pervasive contaminant in Pueblo Canyon and will be assessed further in Sections 5.1.6 through 5.1.8. The remaining COPCs are discussed below.

Polycyclic aromatic hydrocarbons (PAHs) are commonly found in association with petroleum products and are due to incomplete combustion of organic substances. PAHs for which EPA has published toxicity values are generally classified for carcinogenic potential as either class B2 (possible human carcinogen) or class D (inadequate data to determine carcinogenicity). The EPA cancer classification for benzo(a)pyrene is class B2. The EPA cancer classification for benzo(g,h,i)perylene is class D. Other common PAHs that share a class D carcinogenicity classification include acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, and pyrene.

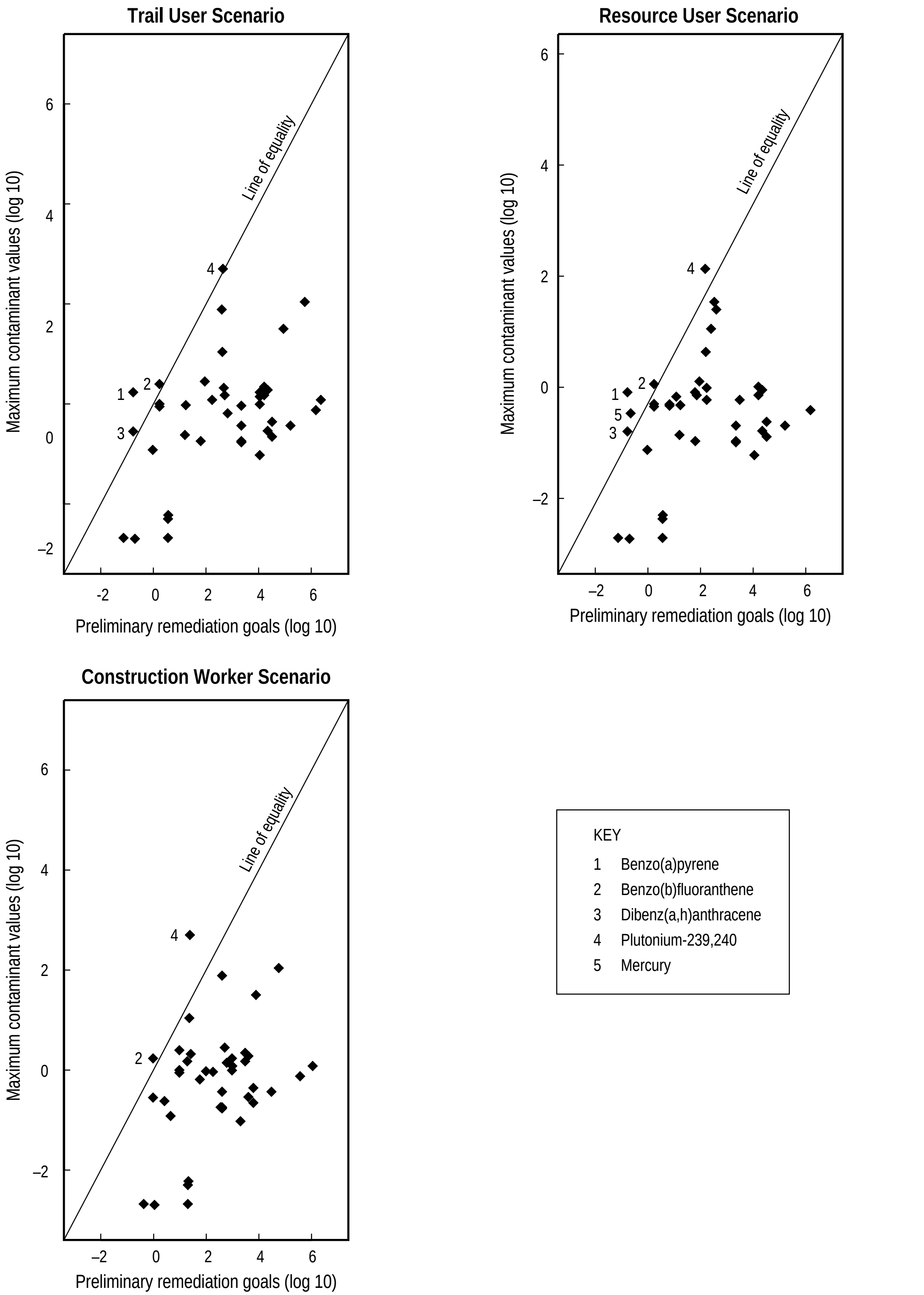
Three PAHs were detected at concentrations above PRGs: benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene. All three compounds are class B2 (possible human carcinogens). Sixteen samples were collected for PAHs: seven in reach P-1 and nine in reach P-4. Five sample results for benzo(a)pyrene exceeded the trail user and resource user PRGs. One sample result exceeded the construction worker PRG. One sample result exceeded the trail user and resource user PRGs for each of benzo(b)fluoranthene and dibenz(a,h)anthracene. Data for neither of these latter compounds exceeded their construction worker PRGs.

PAHs have very low solubilities in water and have strong affinities for surfaces. Consequently, PAHs are bound to sediment particles. The sediments with PAHs exceeding PRGs range in age from the 1950s to the 1990s, suggesting that the source of PAHs in the sediments is not related to a single discrete release. Common nonindustrial sources of PAHs include combustion products from wood and petroleum, asphalt, and tar.

Available data suggest that benzo(a)pyrene, benzo(b)fluoranthene, and dibenz(a,h)anthracene are not pervasive contaminants in Pueblo Canyon. A single sample value for benzo(a)pyrene exceeded trail and resource user PRGs in reach P-4. Six values exceeded PRGs in reach P-1. Possible sources of PAHs in P-1 include roof, parking lot, and road runoff and wood fires in the nearby residential areas; industrial sources of PAHs in Pueblo Canyon originating from the Laboratory have not been identified. Therefore, these contaminants are dropped as COPCs for the assessment in this report. This issue is addressed further in the conclusions of this report.

Benzo(g,h,i)perylene was detected in 5 of 16 samples. EPA has not published toxicity data for this compound. The benzo(g,h,i)perylene detections all occurred with benzo(a)pyrene; the maximum value for benzo(g,h,i)perylene was lower than the benzo(a)pyrene maximum value.

EPA has published noncancer oral toxicity values (reference doses) for acenaphthene, anthracene, fluoranthene, fluorene, naphthalene, and pyrene. These reference dose values are generally associated with an allowable chemical intake that is orders of magnitude larger than that for potent PAH carcinogens such as benzo(a)pyrene and dibenz(a,h)anthracene, when these are evaluated at a target risk level of one excess cancer per million. For example, compare the soil PRGs for these PAHs presented in Table 5.1-1.



Source: PRG.plts

F5.1-1 / PUEBLO CANYON REACH RPT / 102698

Figure 5.1-1. Comparisons of maximum values with PRGs by scenario.

Although EPA has not published a chemical-specific toxicity value for benzo(g,h,i)perylene, the significance of this PAH relative to the other PAHs with which it is associated in the environment (in particular, benzo[a]pyrene) can be inferred from the comparison of soil criteria, evaluation of co-occurrence, and comparison of sample values. The human health impacts associated with exposure to PAHs in the environment can be assessed with reasonable certainty in the absence of specific information on benzo(g,h,i)perylene. Soil criteria associated with the PAHs for which EPA has published slope factor and/or unit risk values are likely to be protective for concomitant exposure to PAHs for which toxicity values have not been derived. Therefore, benzo(g,h,i)perylene is dropped as a COPC for the assessment in this report, which is consistent with the discussion for benzo(a)pyrene.

Mercury is clearly elevated in reach P-1. All 15 samples had detectable concentrations of mercury, of which 11 were above the background value of 0.1 mg/kg. Insufficient data are available on the variations in mercury concentration between geomorphic units to perform the level of assessment applied to plutonium-239,240, although data may be sufficient to estimate average concentrations for some units. Additional assessments to evaluate the potential risk posed by mercury will be necessary in Pueblo Canyon, and additional sampling and analysis may be necessary to support these assessments.

The resource user PRG for mercury at 0.22 mg/kg is two orders of magnitude below the construction worker scenario PRG and three orders of magnitude below the trail user scenario PRG. The controlling pathway for the resource user scenario involves mercury transferred from sediments to fodder and from fodder to meat. Meat from grazing animals is one of the resources evaluated in the resource user scenario. As described below, the scenario assumes that the animals will range and graze 100% of the time on the contaminated sediments. Subsequent reports should evaluate the rangeland required to support typical meat animals relative to the mercury-contaminated surface area of reach P-1. This information can then be used to assess the need for risk mitigation relative to this pathway.

5.1.4 Exposure Assessment

The following exposure scenarios are developed using standard EPA default parameter values, when available. These values are consistent with the parameters for reasonable maximum exposure assessments. Where EPA default parameters are not available, professional judgement has been used in selecting conservative values from other publications or setting site-specific assumptions. Soil ingestion rates are taken from RAGS (EPA 1991, 58234). The averaging time of 30 years for the trail user and resource user and the construction work year of 250 days are also taken from RAGS. Soil inhalation and adult intake rates for fruit, vegetables, and meat are taken from the *Exposure Factors Handbook* (EFH) (EPA 1990, 58694). The proportion of meat (75%) for the resource user is taken from EFH. The trail use and resource use exposure frequencies and durations (75 days per year, one hour per day), the proportion of fruits and vegetables from a reach (10%), the average construction time of one year, and the eight-hour work day are based on professional judgement.

5.1.4.1 Trail User Scenario

The trail user is defined as an adult who uses a given reach 75 days per year during a 30-year period. Each visit to the reach has a duration of one hour. During each hike, the individual ingests 100 mg of soil and inhales 0.25 mg of soil as suspended dust. This scenario is conservative in that it assumes all soil taken into the body originates within geomorphic units that have been inundated by post-1942 floods and thus contain contaminants above background values, although large areas of the canyon floor in each reach are actually uncontaminated.

5.1.4.2 Resource User Scenario

The resource user scenario employs the same temporal parameters as for the trail user and adds the consumption of fruits, vegetables, and meat. The parameters used for adult consumption of fruits, vegetables, and meat are 51 kg/yr, 73 kg/yr, and 36.5 kg/yr, respectively (EFH). The resource users are assumed to obtain 10% of their fruits and vegetables (5.1 kg/yr and 7.3 kg/yr) and 75% of their meat (27 kg/yr) from the reach. These consumption rates are integrated over 30 years, which is consistent with the activity component of the pathway. The fruits and vegetables are assumed to grow in sediments that have the average concentrations of contaminants, and the animals that provide meat are assumed to range and graze exclusively on contaminated sediments; therefore, these assumptions provide conservative estimates of risk.

5.1.4.3 Construction Worker Scenario

The construction worker scenario assumes a 250-day work year with eight-hour days. The duration of the scenario is one year, and all activities are assumed to occur within geomorphic units that contain contaminants above background values. The individual is assumed to ingest soil at a rate of 480 mg/day and to inhale soil as airborne dust at a rate of 2 mg/day. Possible construction activities in Pueblo Canyon under present-day land use conditions include the construction or maintenance of roads and the excavation of trenches for sewer lines or other purposes. These activities would likely involve uncontaminated parts of the canyon floor as well as contaminated areas and would likely have actual durations of less than one year; therefore, this assessment provides conservative estimates of risk.

5.1.5 Toxicity Assessment

The dose conversion factors used in this assessment for plutonium-239,240 assume the values for plutonium-239 in the *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0* (Yu et al. 1993, 58695). These dose conversion factors are referenced to the DOE publications *External Dose-Rate Conversion Factors for Calculation of Dose to the Public* (DOE 1988, 58691) and *Internal Dose Conversion Factors for Calculation of Dose to the Public* (DOE 1988, 58692). The dose conversion factor for plutonium-239 is applied to the plutonium-239,240 results because available data indicate that plutonium-239 is much more abundant than plutonium-240 in sediments at the Laboratory (Gallaher et al. 1997, 59165).

5.1.6 Dose Characterization

Dose characterization in this report is presented in the form of the ratio of the average concentration for the reach or sediment package to the concentration that would result in a dose of 15 mrem/yr for each of the land use scenarios. The dose criterion of 15 mrem/yr follows that recommended by EPA in the memorandum *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* (EPA 1997, 58693). DOE also has dose-based standards for contaminated sites (100 mrem/yr; DOE Order 5400.5, "Radiation Protection of the Public and the Environment."), and these standards apply for as long as DOE maintains administrative control of the site. When DOE transfers land, the EPA standards gain primacy. The EPA standard of 15 mrem/yr is used in this report because part of the canyon is owned by Los Alamos County and other parts are being considered for potential land transfer (DOE 1998, 58671). In addition, there is unrestricted access to the part of Pueblo Canyon currently owned by DOE. The scenario-specific PRGs for plutonium-239,240 that result in an exposure of 15 mrem/yr are 440 pCi/g for the trail user, 150 pCi/g for the resource user, and 24 pCi/g for the construction worker. Note that DOE

Order 5400.5 also provides criteria for evaluating "hot spots," although the sampling density for data collected in this investigation is not sufficient to define such hot spots as discussed in DOE Order 5400.5.

Two weighted averages are calculated for each reach. One is an area-weighted average that uses present-day estimates of average contaminant concentrations in the uppermost sediment packages in each geomorphic unit, as presented in Section 3.3, and unit areas, as presented in Section 2.3. The other is a volume-weighted average that uses vertically weighted concentration estimates where sediment packages are superimposed, using estimated average thicknesses of each package as presented in Section 3.3, and then computes a volume-weighted average concentration to represent the reach. In the area-weighted average all human activity is assumed to be restricted to the area containing contaminated sediments. In the volume-weighted average all human activity is assumed to be restricted to the depths where contamination is above background values, with no mixing with underlying uncontaminated materials. Thus, both averages provide conservative estimates of risk.

These two estimates are necessary to support the dose assessment for the three scenarios. The present-day trail user is exposed to the area-weighted average. The present-day resource user consumes fruits, vegetables, and meat animals that graze on plants growing in the contaminated sediments thereby getting a secondary exposure to the volume-weighted estimate of the contaminant concentrations. The construction worker digging through the sediments would also be exposed to the volume-weighted concentration. An additional consideration for the trail user is that burrowing animal activity eventually results in the vertical averaging of contaminant concentrations, as discussed in Section 4.3.3. There is abundant burrowing animal activity in Pueblo Canyon, suggesting that the trail user will be potentially exposed to the volume-weighted concentrations sometime in the future.

5.1.7 Dose Assessment Results

The dose assessment results for each reach are presented in Tables 5.1-2 through 5.1-8. Each table consists of four parts. The first part is a schematic cross section showing the relative locations of each sediment package in relation to the active channel (c1) and the ground surface. The identifier “ch” refers to channel facies sediment packages, and the identifier “ob” refers to overbank facies sediment packages. The second part is a table that shows the area- and depth-averaged plutonium concentrations for each of the geomorphic units in the reach. The third part is a table showing the dose ratios across the exposure scenarios using average concentrations in upper sediment layers and vertical averages through all contaminated sediment layers. Vertical averages are necessary for the volume concentration estimates at locations in the cross section where sediment packages are superimposed. Table 5.1-2 Part 1 shows a stack of 3 c2b packages. A volume-weighted average of the three concentrations is entered in Table 5.1-2 for c2b under the heading “Vertical-Weighted Average.” That value is also used in Part 3 of the table for computing the PRG ratios in the row labeled “c2b agg.” The row in Part 3 labeled “c2b” uses the plutonium concentration for the uppermost sediment package at the c2b location only. The surface aggregate in Part 4 consists of an area-weighted average of all the surface packages. For Table 5.1-2, these packages are “c1 ch,” ”c2 ob,” “c2b ob,” and “f1 ob.” The volume aggregate in part 4 of Table 5.1-2 uses a volume-weighted contaminant average based on all seven sediment packages in the cross section.

TABLE 5.1-2

DOSE CALCULATION RESULTS FOR REACH P-1 EAST

Part 1. Schematic Cross Section

			f1 ob
c1 ch	c2 ob	c2b ob	
	c2 ch	c2b ob	
		c2b ch	

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1	4.7	4.7
c2	17.6	13.3
c2b	17.6	63.2
f1	10.4	10.4

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1	0.01	0.03	0.20
c2	0.04	0.12	0.73
c2 agg*	0.03	0.09	0.55
c2b	0.04	0.12	0.73
c2b agg	0.14	0.42	2.63
f1	0.02	0.07	0.43

*Vertically weighted aggregate

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	0.02	0.07	0.42
Volume aggregate	0.03	0.08	0.50

TABLE 5.1-3

DOSE CALCULATION RESULTS FOR REACH P-2 WEST

Part 1. Schematic Cross Section

				f1 ob	f2 ob
	c1b ob	c2 ob	c3 ob		
c1 ch	c1b ch	c2 ch	c3 ch		

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1	1.22	1.22
c1b	11.2	2.12
c2	11.21	5.96
c3	11.21	6.70
f1	11.21	11.21
f2	11.21	11.21

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1	<0.01	0.01	0.05
c1b	0.03	0.07	0.47
c1b agg*	<0.01	0.01	0.09
c2	0.03	0.07	0.51
c2 agg	0.01	0.04	0.25
c3	0.03	0.07	0.47
c3 agg	0.02	0.04	0.28
f1	0.03	0.07	0.47
f2	0.03	0.07	0.47
*Vertically weighted aggregate			

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	0.02	0.07	0.42
Volume aggregate	0.01	0.04	0.22

TABLE 5.1-4

DOSE CALCULATION RESULTS FOR REACH P-2 EAST

Part 1. Schematic Cross Section

				f1 ob
	c1b ob	c2 ob	c3 ob	
c1 ch	c1b ch	c2 ch	c3 ch	

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1	0.38	0.38
c1b	2.42	0.50
c2	2.42	0.83
c3	5.31	2.01
f1	2.42	2.42

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1	<0.01	<0.01	0.01
c1b	0.01	0.02	0.10
c1b agg*	<0.01	<0.01	0.02
c2	0.01	0.02	0.10
c2 agg	<0.01	0.01	0.03
c3	0.01	0.04	0.22
c3 agg	<0.01	0.01	0.08
f1	0.01	0.02	0.10

*Vertically weighted aggregate

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	<0.01	0.01	0.09
Volume aggregate	<0.01	0.01	0.03

TABLE 5.1-5
DOSE CALCULATION RESULTS FOR REACH P-3 WEST

Part 1. Schematic Cross Section

				f1 ob	f2 ob
c1 ob	c2 ob	c3 ob	c4 ob		
c1 ch	c2 ch	c3 ch	c4 ch		

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1	1.54	0.90
c2	1.54	0.97
c3	8.65	4.33
c4	8.65	2.02
f1	1.54	1.54
f2	1.54	1.54

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1	<0.01	0.01	0.06
c1 agg*	<0.01	0.01	0.04
c2	<0.01	0.01	0.06
c2 agg	<0.01	0.01	0.04
c3	0.02	0.06	0.36
c3 agg	0.01	0.03	0.18
c4	0.02	0.06	0.36
c4 agg	<0.01	0.01	0.08
f1	<0.01	0.01	0.06
f2	<0.01	0.01	0.06

*Vertically weighted aggregate

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	0.01	0.02	0.10
Volume aggregate	<0.01	0.01	0.06

TABLE 5.1-6

DOSE CALCULATION RESULTS FOR REACH P-3 EAST

Part 1. Schematic Cross Section

				f1 ob	f2 ob
	c2 ob	c3 ob	c4 ob		
c1 ch	c2 ch	c3 ch	c4 ch		

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1	0.89	0.89
c2	1.54	1.06
c3	8.65	3.39
c4	8.65	1.69
f1	1.54	1.54
f2	1.54	1.54

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1	<0.01	0.01	0.04
c2	<0.01	0.01	0.06
c2 agg*	<0.01	0.01	0.04
c3	0.02	0.06	0.36
c3 agg	0.01	0.02	0.14
c4	0.02	0.06	0.36
c4 agg	<0.01	0.01	0.07
f1	<0.01	0.01	0.06
f2	<0.01	0.01	0.06
*Vertically weighted aggregate			

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	<0.01	0.01	0.08
Volume aggregate	<0.01	0.01	0.05

TABLE 5.1-7

DOSE CALCULATION RESULTS FOR REACH P-4 WEST

Part 1. Schematic Cross Section

							f1 ob	f1a ob	f2 ob
c1,1b ob	c2a,b,c ob	c3 ob	c4a ob	c4b ob	c5 ob	c6 ob			
c1,1b ch	c2a,b,c ch	c3 ch	c4a-uc ch	c4b-uc ch	c5-uc ch	c6 ch			
			c4a-mc ch	c4b-lc ch	c5-lc ch				
			c4a-lc ch						

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1,1b	5.99	1.79
c2a,b,c	5.99	1.79
c3	5.99	1.79
c4a	5.99	1.84
c4b	5.99	3.5
c5	5.99	3.5
c6	37.8	8.58
f1	5.99	5.99
f1a	0.38	0.38
f2	5.99	5.99

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1,1b	0.01	0.04	0.25
c1,1b agg*	<0.01	0.01	0.07
c2a,b,c	0.01	0.04	0.05
c2a,b,c agg	<0.01	0.01	0.07
c3	0.01	0.04	0.25
c3 agg	<0.01	0.01	0.07
c4a	0.01	0.04	0.25
c4a agg	<0.01	0.01	0.08
c4b	0.01	0.04	0.25
c4b agg	0.01	0.02	0.15
c5	0.01	0.04	0.25
c5 agg	0.01	0.02	0.15
c6	0.09	0.25	1.58
c6 agg	0.02	0.06	0.38
f1	0.01	0.04	0.25
f1a	<0.01	<0.01	0.02
f2	0.01	0.04	0.25

*Vertically weighted aggregate

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	0.02	0.06	0.35
Volume aggregate	0.01	0.02	0.13

TABLE 5.1-8

REACH P-4 EAST DOSE CALCULATION RESULTS

Part 1. Schematic Cross Section

			f1-u ob	f2 ob
c1,1b ob	c2a,b,c ob	c3 ob	f1-l ob	
c1,1b ch	c2a,b,c ch	c3-uc ch		
		c3-mc ch		
		c3-lc ch		

ch = channel facies
ob = overbank facies

Part 2. Plutonium Concentrations

Unit	Upper Sediment (pCi/g)	Vertical-Weighted Average (pCi/g)
c1,1b	5.99	1.79
c2a,b,c	5.99	1.79
c3	5.99	1.88
f1	5.99	4.45
f2	5.99	5.99

Part 3. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario and Package

	Trail User	Resource User	Construction Worker
c1,1b	0.01	0.04	0.25
c1,1b agg*	<0.01	0.01	0.07
c2a,b,c	0.01	0.04	0.25
c2a,b,c agg	<0.01	0.01	0.07
c3	0.01	0.04	0.25
c3 agg	<0.01	0.01	0.08
f1	0.01	0.04	0.25
f1 agg	0.01	0.03	0.19
f2	0.01	0.04	0.25
*Vertically weighted aggregate			

Part 4. Potential Plutonium Exposures Relative to 15 mrem/yr by Scenario

	Trail User	Resource User	Construction Worker
Surface aggregate	0.01	0.04	0.25
Volume aggregate	<0.01	0.01	0.09

The key information on potential human health risk from plutonium-239,240 in each reach is presented in the fourth part of the dose assessment tables, where a value exceeding 1.0 would indicate a potential dose exceeding 15 mrem/yr and thus exceeding the EPA dose limit. The highest values for each scenario are found in reach P-1 East (Table 5.1-2), although none of these values approach 1.0. The maximum value for the trail user scenario is 0.04, or only 4% of 15 mrem/yr, and the maximum value for a resource user is 0.09. The highest potential risk from plutonium-239,240 in the sediments of Pueblo Canyon is associated with the construction worker scenario, although the maximum value of 0.55 is still below the level that would indicate a potentially unacceptable risk. In addition, because of the conservative assumptions built into this scenario, the actual risk to a construction worker would likely be even less. In summary, these calculations indicate that the levels of plutonium in the sediments of Pueblo Canyon are not high enough to constitute an unacceptable human health risk under conditions of present-day land use. Thus, there is no need for immediate remedial actions from the standpoint of human health.

The dose ratios presented in the third part of the dose assessment tables indicate the estimated dose that would exist if all exposure under each scenario occurred solely within single geomorphic units. Because activities would actually occur in some combination of units, single package assessments clearly provide unrealistic estimates of risk, although they are valuable in indicating the relative importance of the different units. For example, dose ratios in only two units, the c2b agg unit in P-1 East and the c6 unit in P-4 West, exceed 1.0 under the construction worker scenario. Thus, these areas and other areas with similar plutonium concentrations in unsampled reaches would be logical targets for remedial action if it was decided that the present concentrations of plutonium presented unacceptable risk to construction workers. The information in the second part of each table shows the weighted concentrations that are associated with the PRG ratios in part three.

5.1.8 Uncertainty Analysis

The conclusions of the COPC evaluation and the preliminary human health risk analysis are that there is no immediate need for remediation in Pueblo Canyon based on the plutonium-239,240 data and that additional data collection for mercury may be necessary to conduct additional assessments. An assessment of range requirements for meat animals relative to the contaminated area of reach P-1 may also be necessary. Sources of uncertainty in these conclusions include using the analyzed reaches to represent all of Pueblo Canyon downstream from contaminant sources, reliance on plutonium-239,240 to represent the contaminant signature for Pueblo Canyon, and area and volume estimates for the sediment packages.

The primary source of uncertainty about the conclusion that there is no need for immediate remedial action with regard to plutonium-239,240 is whether the areas with highest plutonium concentrations have been identified in Pueblo Canyon. Within the sampled reaches, which represent 35% of the total length of Pueblo Canyon downstream from Acid Canyon, it is considered unlikely that plutonium concentrations in any area greatly exceed those measured at sample sites. In addition, if higher levels of plutonium exist in sampled reaches, the area and volumes of such sediment would be small and unlikely to significantly affect average concentrations for the reach. Larger uncertainties exist concerning the unsampled reaches. It is possible that plutonium concentrations in fine-grained sediment deposits in unsampled reaches dating to the period of effluent releases from Technical Area (TA) -45 could exceed those measured in this investigation, particularly in the area between reaches P-1 East and P-2 West. However, it is unlikely that the area or volume of such deposits would be sufficient to cause exceedances of the PRGs.

Additional sources of uncertainty include the dose conversion factors for radionuclides, slope factors for carcinogens, reference concentrations for noncarcinogens, and exposure factors and uptake ratios for plant and animals. These latter sources of uncertainty will be addressed in future reports when all pathways, including surface water and groundwater, are addressed. For this report, values for these parameters were used that are conservative and therefore protective of human health.

Uncertainties concerning the use of plutonium-239,240 analyses to identify sites containing other COPCs are considered minor because of the pervasive occurrence of plutonium above background values in all young sediment deposits in Pueblo Canyon. However, because of the lack of clear collocation between plutonium-239,240 and the inorganic and organic COPCs, and the relatively small data set for these COPCs, the maximum and average concentrations for the inorganic and organic COPCs may not be well constrained. Excluding plutonium, mercury may present the highest potential human health risk in Pueblo Canyon, although all mercury results in reaches P-2, P-3, and P-4 are below PRGs. Additional sampling and analysis may be required to provide improved estimates of average mercury concentration in reach P-1 for use in risk assessments

Additional uncertainty in this analysis pertains to the area- and volume-weighted estimates of plutonium concentration. This uncertainty has not been quantitatively evaluated but, because of the conservative biases discussed here, is considered to be small enough to support the conclusion that PRGs would not be exceeded. The area-weighted averages are believed to be more accurate than the volume-weighted averages because sampling tended to be biased toward upper sediment layers and because the surface areas of geomorphic units are usually well defined. Uncertainties in the depth estimates for the packages are more difficult to ascertain. Depths were biased to higher values to avoid underestimating contaminant inventories, and volume-weighted averages may tend to be weighted too heavily toward the thickest units. However, volume-weighted plutonium concentrations in geomorphic units with thin layers of contaminated sediment would tend to be overestimated because of the assumption that there was no mixing with deeper uncontaminated sediment. In summary, the assumptions used in these calculations should result in a sufficiently conservative estimate of risk, indicating that there is no need for immediate remedial action with regard to potential human health risk.

5.2 Ecological Screening Assessment

There are two phases of the ecological screening assessment as presented in Kelly et al. (1998, 57916) and followed in this report: the scoping evaluation and the screening evaluation. The scoping evaluation includes (1) the data assessment step, which identifies the list of COPCs for the reaches; (2) the problem formulation step for the specific reaches under investigation; and (3) the bioaccumulation evaluation step, which evaluates the level of concern for persistent bioaccumulation and/or biomagnification from contaminants in the reaches. The basis for Pueblo Canyon-specific problem formulation is found in the scoping checklist in Appendix F. The scoping checklist is a useful tool for organizing existing ecological information and focusing the site visit on the information needed to develop the site conceptual model (SCM). The scoping checklist also provides the basis for evaluating the adequacy of the data for ecological risk screening.

The screening evaluation includes the calculation of HQs and hazard indices (HIs) for all COPCs and all appropriate screening receptors. The HQ can be thought of as the ratio of the calculated exposure dose to the receptor (based on contaminant levels in the reach) to a dose that has been determined to be acceptable (based on toxicity studies for the receptor). An HI is a sum of HQs, across contaminants with like effects, for a given screening receptor. An HQ or HI greater than 1 is considered an indicator of potential adverse impacts, and the chemical constituents resulting in an HQ or HI greater than 1 are identified as contaminants of potential ecological concern (COPECs). HQ calculations require toxicity, bioconcentration, and bioaccumulation information for all chemicals for all receptors. This report will not include a quantitative screening evaluation because the required toxicity, bioconcentration, and bioaccumulation information are not available for aquatic receptors. To provide some information for a qualitative uncertainty analysis, maximum COPC concentrations were compared with the ecological screening levels for the most sensitive terrestrial receptors.

An uncertainty analysis follows the COPEC identification, which describes the key sources of uncertainty in the screening assessment. The uncertainty analysis can result in adding chemical constituents to or removing them from the list of COPECs. This report contains a qualitative uncertainty analysis to help understand potential data gaps associated with evaluating ecological risk.

The last part of the screening assessment is to interpret screening results in the context of a risk management decision. In general, possible decisions include a recommendation of the appropriate corrective action, in terms of ecological concerns. Possible recommendations include ecological no further action (NFA), voluntary corrective action (VCA), expedited cleanup (EC), voluntary corrective measure (VCM), and corrective measures study (CMS), any of which will be incorporated into an integrated risk management decision to include human health risk evaluations, groundwater and surface water issues, and other applicable regulations. In this report, the interpretation section will be used to recommend the type of additional data for the Pueblo Canyon reaches that are needed for ecological risk characterization.

5.2.1 Scoping

5.2.1.1 Data Assessment

The approach taken to characterize the sediments in Pueblo Canyon was designed to provide information on the nature and extent of contamination. By using information on known contaminant sources and laboratory analytical data, the COPC list for Pueblo Canyon sediments was established in Section 3.1. The COPCs have been established based on statistical and graphical analysis of the data at a reach level.

5.2.1.2 Problem Formulation

The purpose of the screening-level ecological risk problem formulation for the canyons is to provide information to (1) determine if ecological receptors can be affected by a release; (2) determine how the sediments should be aggregated spatially for screening and establish the functional/operational boundaries of the assessment; and (3) gather information to develop the SCM (e.g., what are the contaminant sources, dominant transport pathways and exposure routes, and potential receptors).

Terrestrial ecological receptors are abundant throughout Pueblo Canyon, where the dominant plants include ponderosa pine, fir, shrub oak, chamisa, forbs, and grasses. Many areas have evidence of burrowing mammals, which represents both a potentially exposed animal population and a mechanism for contaminant redistribution. Limited areas have aquatic communities, and these areas include the active channel portion of reach P-1 and the active channel downgradient of the Bayo Canyon Wastewater Treatment Plant (WWTP) (reaches P-3 East and P-4). The surface water in reach P-1 likely originates from a combination of natural sources (a seep located near the Acid Canyon confluence) and runoff from residences. In the recent past, physical disturbance associated with installation and maintenance of the residential sewer line has affected the type and distribution of plants and animals. This sewer line is located in or near the active canyon floor from reach P-1 downstream past P-2 West to Kwage Canyon and on the lower canyon wall from P-2 East to P-3 West. The primary impact of this disturbance was to redistribute or bury some of the contaminated sediment packages. The disturbed areas were also noted to have early successional plant species (grasses and forbs).

Threatened and endangered (T&E) species are potential receptors for contaminant releases in Pueblo Canyon sediments. Specifically, the Mexican spotted owl and the peregrine falcon may roost or forage in Pueblo Canyon (Koch 1998, 59116). Thus, the kestrel screening receptor with an all flesh diet will serve as a surrogate for these avian T&E receptors in the screening calculations.

Sediment data were collected on a reach basis, and within reaches samples were collected from a variety of geomorphic units and sediment facies. The reaches were selected to reflect the range in contaminant concentrations present within Pueblo Canyon sediments and to represent west-to-east geographic variations in the size of contaminated geomorphic units.

Historical contaminant releases that affected the sediments in Pueblo Canyon could have occurred from a series of potential release sites (PRSs) in the Pueblo Canyon watershed, as summarized in Section 1.3-2; that information will not be repeated here. The most significant contaminant source in the watershed was the radioactive liquid waste treatment plant at former TA-45, and other PRSs are present at TA-0, TA-31, and TA-73.

For the Pueblo Canyon investigation, the primary impacted media are (1) surface soil in the canyon floodplain; (2) sediment in the active channel and adjacent abandoned channel surfaces (c1 and c2 geomorphic units); and (3) surface water derived from seeps, springs, storm water runoff, or permitted municipal waste water discharges. In addition, the shallow alluvial groundwater in parts of Pueblo Canyon may carry colloidal and dissolved contaminants.

The most important transport mechanism for contaminants in channel and floodplain units is lateral and vertical erosion of historical sediment deposits by surface water runoff, particularly in floods. Uncontaminated surface water could become contaminated by suspension or dissolution of contaminated soil or sediment. Another important release mechanism is the suspension of dry particulates by eolian processes, which makes air a secondary contaminated media. If the shallow alluvial groundwater is contaminated, contaminants could become available to ecological receptors in springs and seeps.

The ecological SCM is presented graphically in Figure 5.2-1. The SCM identifies which exposure pathways represent major, minor, unlikely, or no pathway to ecological receptors. Exposure pathways to terrestrial receptors can occur through air (inhalation or deposition of particulates); surface soil (root uptake and rainsplash on plants, food web transport to plants and animals, incidental ingestion of soil, dermal contact with contaminated soil, and external radiation); and surface water or active channel sediments (root uptake and rainsplash on plants, food web transport to animals, incidental ingestion of water and sediment, dermal contact with contaminated water or sediment, and external radiation from sediment). The major soil-related exposure pathways are expected to be food web transport and incidental ingestion of contaminated soil. Completion of the external gamma radiation pathway for soil or sediment/surface water is expected to be unlikely in Pueblo Canyon because of the observation of a single strong gamma-emitting radionuclide (cesium-137) only marginally above the background value (in reach P-1). The major sediment/surface water -related exposure pathways are expected to be food web transport and incidental ingestion of contaminated soil because of the presence of aquatic organisms in reaches P-1 and P-4. However, the importance of the water/sediment pathways are questionable because of the limited extent of active channel sediments and surface water along the entire length of Pueblo Canyon. Exposure to vapors is not a complete pathway because of the lack of volatile contaminants. Exposure to airborne particulates is expected to be a minor pathway because of the limited amount of contamination on the ground surface. Lastly, the remaining pathways that are related to exposure to surface soil (root uptake/rainsplash and dermal contact) and surface water/sediment (dermal contact) are expected to be minor because of the limited amount of contamination expressed at the ground surface coupled with the low absorption potential of the primary contaminant (plutonium) through skin or roots.

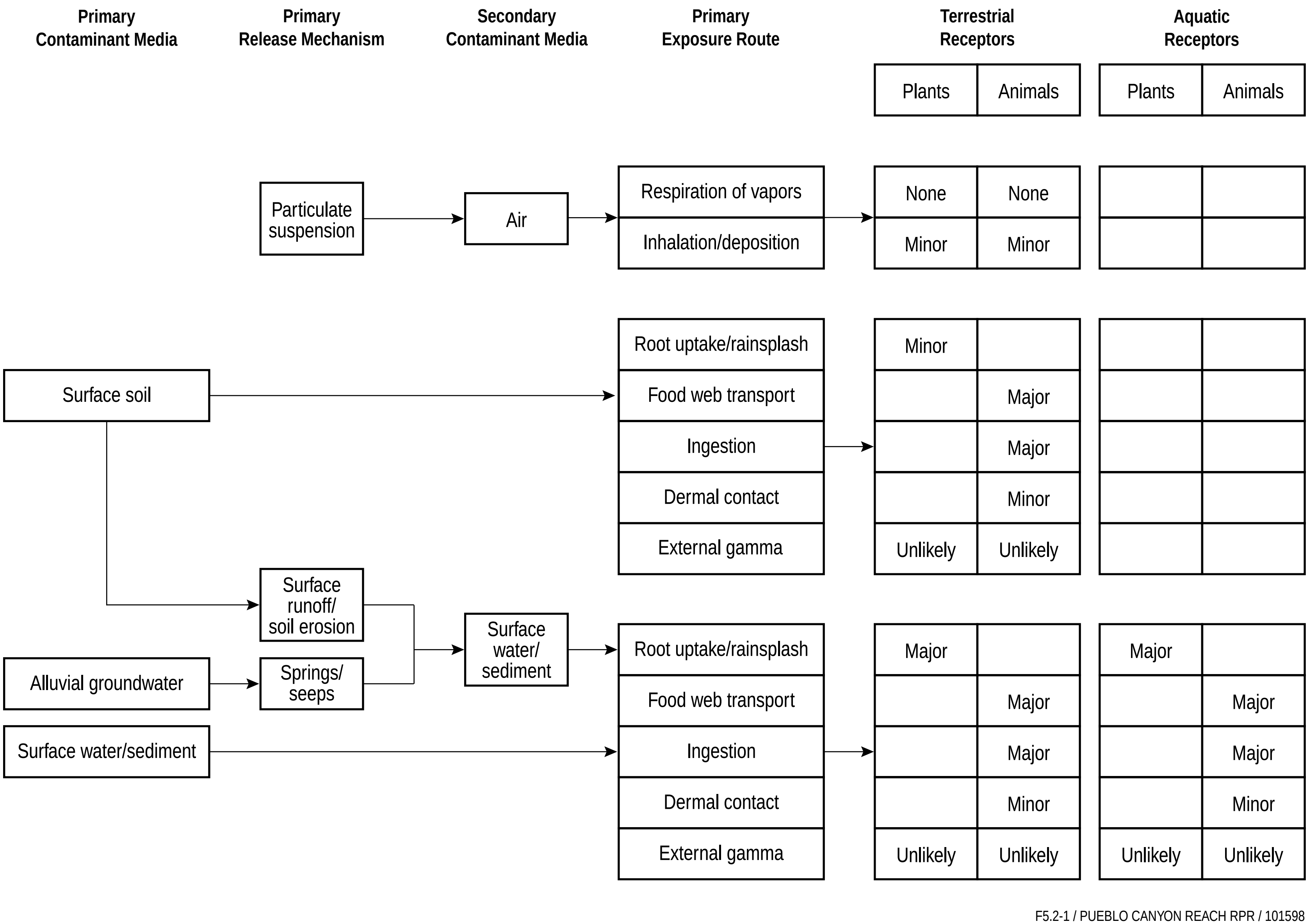


Figure 5.2-1. Conceptual site model of ecological receptors.

Typically all complete exposure pathways should be at least qualitatively evaluated in the screening evaluation. However, because of the lack of screening values for aquatic receptors, the screening evaluation presented below will evaluate only soil-related exposure pathways to terrestrial receptors (exclusive of dermal exposure and inhalation of particulates).

5.2.1.3 Bioaccumulator Evaluation

Several analytes detected above background values in the Pueblo Canyon reaches are potential bioaccumulators (see Table 5.2-1). However, most of these COPCs are measured at values only marginally above detection limits or background values. Thus, it is unlikely that significant bioaccumulation will occur for most of these chemicals. To better address the impact of the potential bioaccumulating chemicals and other COPCs on ecological receptors, a screening-level ecological risk assessment is appropriate. The significance of bioaccumulation will be an important topic in the uncertainty analysis of this screening-level risk assessment.

TABLE 5.2-1

COPCs FOR THE ECOLOGICAL SCREENING EVALUATION

Analyte Group	Analytes
Inorganic Chemicals	Antimony, cadmium*, copper*, lead*, mercury*, selenium*, silver, zinc
Radionuclides	Americium-241*, Cesium-137*, plutonium-238*, plutonium-239,240*, strontium-90*, tritium
Pesticides	Aldrin, δ-BHC*, α-chlordane*, γ-chlordane*, 4,4'-DDT
PCBs	Aroclor-1254*; Aroclor-1260*
SVOCs	Acenaphthene*, acenaphthylene, anthracene*, benz(a)anthracene*, benzo(a)pyrene*, benzo(b)fluoranthene*, benzo(g,h,i)perylene*, benzo(k)fluoranthene*, benzoic acid, bis(2-ethylhexyl)phthalate*, carbazole, chrysene*, di-n-octylphthalate*, dibenz(a,h)anthracene*, dibenzofuran, fluoranthene*, fluoranthene*, fluorene*, indeno(1,2,3-cd)pyrene*, 2-methylnaphthalene, naphthalene, phenanthrene*, pyrene*
*Potential persistent bioaccumulator as defined by the New Mexico Environment Department	

5.2.2 Screening Evaluation

The formal, quantitative screening evaluation will be made after ecological screening levels (ESLs) are developed for Laboratory aquatic receptors. The aquatic receptor screening evaluation also requires surface water sample data, which is not currently available for Pueblo Canyon. However, to help support an evaluation of the adequacy of the existing data for future canyon-wide ecological risk assessments, the *relative* hazard posed by COPCs to terrestrial ecological receptors was assessed. This analysis will help identify which COPECs represent potential terrestrial ecological risk drivers. Thus, these COPECs may require additional data collection to address only ecological risk uncertainties.

Table 5.2-2 provides the maximum detected sample result (except for antimony, which was never detected and for which the maximum detection limit is provided) for each Pueblo Canyon COPC and the corresponding minimum terrestrial ESL. This same information is presented graphically in Figure 5.2-2, where the x-axis plots the maximum value for each COPC in Pueblo Canyon and the y-axis plots the minimum terrestrial ESL[1]. The y-axis represents a conservative estimate of the exposure point concentrations for ecological receptors, and the future canyon-wide assessments will use more realistic estimates of exposure. Symbols that plot above the dashed line (the line of equality or y = x) represent chemicals (COPECs) that pose potential ecological risk (or HQ > 1). These analytes will be considered COPECs for the qualitative uncertainty analysis and interpretation sections below. This COPEC list is considered only preliminary because aquatic receptors and pathways have not been evaluated. Thus, other COPECs will likely be identified in the canyon-wide ecological assessment of sediment and surface water contamination in the Pueblo Canyon watershed. The nine COPECs that the highest potential risk to terrestrial ecological receptors, listed in order of HQ, are mercury; plutonium-239,240; bis(2-ethylhexyl)phthalate; antimony; zinc; dichloro diphenyl trichloroethane (DDT); Aroclor-1254; lead; and selenium. The qualitative uncertainty analysis and interpretation sections of the screening-level ecological risk assessment will focus on these nine COPECs.

Because of the potential T&E species exposure to these COPCs, it is important to note those COPCs where the surrogate ecological receptor (kestrel with a flesh diet) has the lowest ESL. Bis(2-ethylhexyl)phthalate is the only COPC where the kestrel has the lowest soil ESL (Table 5.2-2).

5.2.2.1 Uncertainty Analysis

This qualitative uncertainty analysis will consider the nine COPECs identified in the qualitative screening evaluation section. These COPECs include one radionuclide, five inorganic chemicals, and three organic chemicals. Seven of these chemicals are also considered potentially persistent bioaccumulators. Each of these COPECs is briefly discussed below.

Plutonium-239,240. Because of the extensive discussion of plutonium-239,240 in the human health risk evaluation and the large database for this COPEC, additional discussion of the uncertainty relative to ecological receptors is not needed. Thus, it is assumed that uncertainties associated with regard to plutonium-239,240 for evaluating ecological risk are acceptable.

Antimony. Significant data quality issues affect the data assessment of this COPEC, as discussed in Sections 3.1 and 3.2. The data rejected for reach P-4 are not expected to impact this assessment, as two valid antimony sample results remain for reach P-4. These two P-4 samples are consistent with the range of nondetect sample results obtained for the other reaches. No antimony detects were observed in the Pueblo Canyon sediment samples, and it is retained for data assessment only because of elevated detection limits that were higher than the background value. However, detection limits were elevated in only 17 of 44 inorganic chemical analyses from the Pueblo Canyon sediments. This evidence indicates that antimony is probably not elevated above the background value and should not be considered further in data assessment.

[1] The ratio of the y-axis to the x-axis value is equivalent to the HQ discussed above, and all supporting information for the derivation of terrestrial ESLs is postponed until the complete ecological risk assessment can be done that covers both terrestrial and aquatic receptors. Readers can review the basic models to calculate terrestrial ESLs in Kelly et al. (1998, 57916, Chapter 4).

TABLE 5.2-2

MAXIMUM DETECTED SEDIMENT CONCENTRATIONS AND ECOLOGICAL SCREENING LEVELS

Analyte	Pueblo Maximum Sample Result (mg/kg)	Minimum ESL (mg/kg)	Screening Receptor with Minimum ESL[a]
Organic Chemicals			
Aroclor-1254	0.238	0.14	Robin
Aroclor-1260	0.117	0.15	Shrew
Aldrin	0.00211	N/A[b]	N/A
δ-BHC	0.00197	N/A	N/A
α-Chlordane	0.00497	1.7	Robin
γ-Chlordane	0.00211	1.7	Robin
4,4'-DDT	0.00599	0.0021	Robin
Acenaphthene	0.219	4.5	Mouse
Acenaphthylene	0.44	N/A	N/A
Anthracene	0.369	440	Mouse
Benz(a)anthracene	1	3.9	Shrew
Benzo(a)pyrene	1.7	3.8	Shrew
Benzo(b)fluoranthene	2.5	3.7	Shrew
Benzo(g,h,i)perylene	0.86	2.2	Fox
Benzo(k)fluoranthene	0.95	3.7	Shrew
Benzoic acid	0.75	8.4	Mouse
Bis(2-ethylhexyl)phthalate	2.8	0.24	Kestrel[c]
Carbazole	0.18	N/A	N/A
Chrysene	1.2	3.9	Shrew
Dibenz(a,h)anthracene	0.28	2.3	Fox
Dibenzofuran	0.18	100	Plant
Di-n-octylphthalate	0.094	330	Shrew
Fluoranthene	1.9	53	Shrew
Fluorene	0.294	30	Invertebrate
Indeno(1,2,3-cd)pyrene	0.88	2.5	Fox
2-Methylnaphthalene	0.167	11	Mouse
Naphthalene	0.374	21	Mouse
Phenanthrene	1.505	4.4	Mouse
Pyrene	2.2	32	Shrew
Inorganic Chemicals			
Antimony	4.9[d]	1.0	Mouse
Cadmium	0.92	3	Plant
Copper	31.5	50	Invert
Lead	77.3	50	Plant
Mercury	0.65	0.012	Robin
Selenium	0.98	0.85	Robin
Silver	1.7	2	Plant
Zinc	113	50	Plant
Radionuclides[e]			
Americium-241	11.48	47	Robin
Cesium-137	1.53	42	Robin
Plutonium-238	2.078	31	Robin
Plutonium-239,240	502.01	33	Robin
Strontium-90	1.4	150	Robin
Tritium	1.21	41,000	Mouse

a. ESLs are calculated based on the methodology presented in Kelly et al. (1998, 57916).
b. N/A = not applicable
c. Kestrel was modeled with 100% flesh diet to mimic a falcon.
d. Antimony result is *not* a detect.
e. Radionuclides have units of pCi/g.

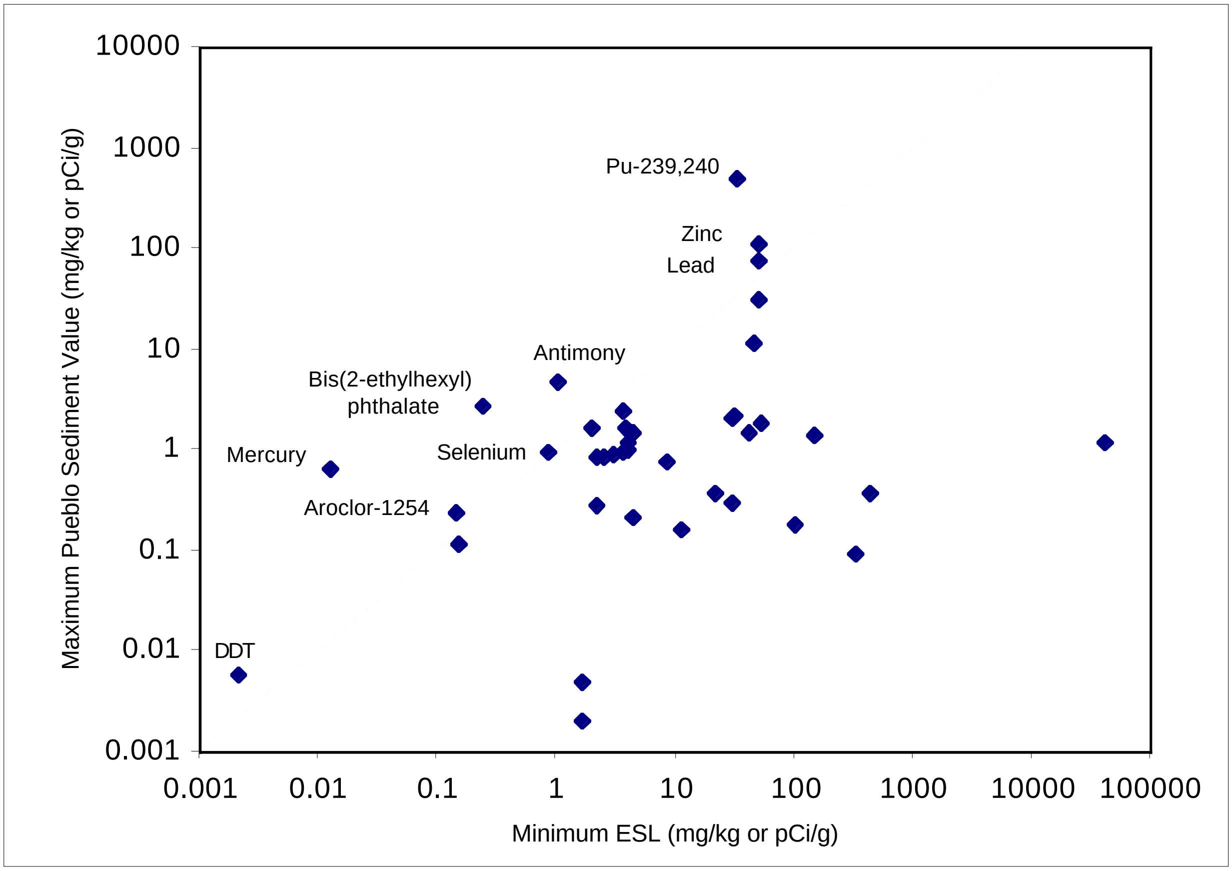


Figure 5.2-2. Preliminary comparison of the relative hazard posed by Pueblo Canyon COPCs to terrestrial ecological receptors.

Lead. Lead was measured at up to three times background value in reach P-1; it was also elevated in reach P-2 and possibly reach P-3. The chemical form of lead is important to the bioavailability and toxicity of lead in the environment. Uncertainty in bioavailability of lead could be addressed through literature searches of existing data sources or new data collection.

Mercury. Mercury was clearly measured above the background value in Pueblo Canyon sediments (especially in reach P-1) and warrants a toxicity-based evaluation. Recall that reach P-1 also has aquatic receptors; therefore, potential effects on aquatic receptors are especially relevant in reach P-1. The importance of mercury as a risk to either aquatic or terrestrial ecological receptors depends on whether it exists as organic mercury or elemental mercury. Organic mercury is readily absorbed by animals, and it is more potent toxicologically in this form. Uncertainty could be reduced through further sediment analyses to determine the form of mercury present. Surface water samples should be collected to determine the amount of total mercury, and consideration should be given to determining if organic mercury is present in Pueblo Canyon surface water.

Selenium. Some data quality issues affect selenium, particularly in relation to detection limits. As discussed in Sections 3.1 and 3.2 and Appendix E, there is only weak evidence that selenium is above the background value, which suggests that uncertainties associated with calculating the representative concentration for exposure to selenium should be acceptable.

Zinc. Zinc is clearly elevated above the background value, especially in reach P-1. Information on the toxicity and bioaccumulation of specific chemical forms of zinc comprise the largest source uncertainty for this COPEC. This uncertainty could be addressed through literature searches of existing data sources.

Aroclor-1254. This COPEC was detected in only a single sample at approximately five times the typical detection limit; the median and mean values for Aroclor-1254 are nondetects. The related chemical, Aroclor-1260, was also detected in the Pueblo Canyon reaches at lower concentrations. Because of the apparently limited distribution of detectable aroclors (also known as polychlorinated biphenyls [PCBs]) in the Pueblo Canyon sediments, it would be difficult to sample sediments with standard laboratory analytical methods to better characterize PCB concentrations. Uncertainty in PCB bioaccumulation could be addressed through literature searches of existing data sources.

Bis(2-ethylhexyl)phthalate. This plasticizer was detected in a single sample collected upstream of Acid Canyon in P-1 West. The detected result was 10 times the typical detection limit. Because this COPEC was not associated with the main contaminant source term in Acid Canyon, it could be related to numerous nonpoint sources in the upper Pueblo Canyon watershed. As noted in Section 3.2, no semivolatile organic chemical analyses, and therefore no bis(2-ethylhexyl)phthalate sample results, are available for reaches P-2 and P-3. This data gap causes some uncertainty in the maximum value for this COPEC. In addition, the most sensitive receptor for this COPEC was the kestrel, which is a surrogate for T&E species. However, additional sediment samples for this COPEC do not seem warranted because of its infrequent detection in sediments (1 of 16 samples) and lack of an identified Laboratory-related source for this chemical.

DDT. DDT was detected in 3 of 30 samples collected in Pueblo Canyon. The concentration in the detects is roughly twice the typical detection limit for DDT. Although DDT has known ecological effects (especially for birds) and is a potentially persistent bioaccumulator, uncertainty in calculating the representative concentration for exposure to DDT would not be reduced through additional sediment data collection because of the infrequent detection of this COPEC. The potential for DDT bioaccumulation could be addressed through literature searches of existing data sources.

5.2.2.2 Interpretation

Several COPECs have been identified in Pueblo Canyon sediments, and further assessments of ecological risk will be performed. However, the lack of obvious contaminant-related ecological impacts in Pueblo Canyon suggests that there is no need for immediate remedial action with regard to ecological risk.

Most of the uncertainties in potential ecological risk could be addressed through literature searches of existing data sources to estimate bioaccumulation of mercury, PCBs, and DDT in the Pueblo Canyon food web. The form of mercury present in Pueblo Canyon sediments is important to evaluating mercury toxicity and could be determined through collection of a limited number of additional sediment samples.

Another obvious data gap in Pueblo Canyon is surface water in reaches P-1, P-3 West, and P-4. Water quality in reaches P-3 West and P-4 are impacted by permitted releases from the Bayo Canyon WWTP. Surface water data are needed to develop a comprehensive ecological risk assessment of Pueblo Canyon.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

This section summarizes conclusions from this investigation, highlights key remaining uncertainties related to contaminated sediments in Pueblo Canyon, and provides recommendations concerning possible additional assessments, data collection, and remedial action. The human health and ecological screening assessments presented in this report are preliminary and are intended to identify any need for immediate remedial action or additional data collection from the standpoint of potential risk. These preliminary assessments consider only present-day land use scenarios and the potential risk presented by contaminated sediments. More comprehensive risk assessments will be presented in one or more future reports on Pueblo and Los Alamos Canyons that will incorporate the results of ongoing groundwater investigations and additional sediment investigations and that may consider other land use scenarios.

6.1 Nature and Sources of Contaminants

The primary chemicals of potential concern (COPCs) in the sediments of Pueblo Canyon are radionuclides that were discharged from former Technical Area (TA) -45 into Acid Canyon. The most significant radionuclide in terms of potential human health risk is plutonium-239,240. Radionuclides that clearly have the same source and are collocated with plutonium-239,240 include americium-241, plutonium-238, and possibly tritium; the potential risks associated with these other radionuclides are minor relative to plutonium-239,240. Cesium-137 and strontium-90 are also known to have been released from TA-45 and were detected above background values in a single sample. Because of a statistical similarity to background data, the primary source for cesium-137 in Pueblo Canyon sediments is inferred to be worldwide fallout and not Laboratory operations. In contrast, the strontium-90 data indicate a statistical difference from background and therefore suggest actual releases from TA-45.

A series of inorganic COPCs have been identified in the sediments of Pueblo Canyon that are not clearly collocated with plutonium-239,240 and that appear to have been derived from multiple sources, although the relative contributions from different sources have not been defined. The most significant inorganic COPC with regard to potential human health or ecological risk is mercury. Mercury has its highest concentrations in reach P-1, and data from this investigation and previous investigations indicate sources both in the Acid Canyon basin and in the Pueblo Canyon basin upstream from Acid Canyon. Release sites may include TA-45 and the Pueblo Canyon Wastewater Treatment Plant (WWTP), but no sediment samples have been collected upstream from either of these sites; therefore, the possibility of other sources cannot be ruled out. Additional sampling and analysis would be required if it is necessary to determine the source of the mercury with more certainty in the context of evaluating risk and potential remedial actions.

Several inorganic COPCs (cadmium, lead, silver, and zinc) have their highest concentrations in reach P-1 and have physical distributions that are similar to mercury. These contaminants may also have multiple sources within the upper Pueblo Canyon watershed. Another inorganic COPC, copper, may have been released from the same sites, but the maximum value for copper was obtained downstream in reach P-2 West, suggesting an additional source downstream of Acid Canyon as well. Additional sampling and analysis would be required if it is necessary to determine the source of these contaminants with more certainty.

The remaining inorganic COPCs, antimony and selenium, have significant data quality issues that limit understanding of the potential significance of these chemicals in Pueblo Canyon sediments. It is possible that one or both are present only at background levels. Additional sampling and analysis would be required if it is necessary to determine if these chemicals are present above background values and, if so, to determine their sources.

Twenty-nine organic COPCs have been measured at low concentrations in the sediments of Pueblo Canyon and appear to have been derived from multiple sources, although none of the sources for these organic COPCs have been clearly identified. These chemicals include polychlorinated biphenyls (PCBs), pesticides, plasticizers, and polycyclic aromatic hydrocarbons (PAHs). Sources of these chemicals could potentially include both former Laboratory sites and urban areas of the Los Alamos townsite (e.g., parking lot and roadway runoff as a source of PAHs). For many of these COPCs naturally occurring materials such as charcoal could also have potentially provided results above detection limits. Additional sampling and analysis would be required if it is necessary to determine sources of the organic COPCs with more certainty.

6.2 Present Distribution of Contaminants

Plutonium-239,240 and other contaminants within Pueblo Canyon have been widely distributed by floods during the past 55 years. Sediment with plutonium concentrations above background values is present along the full length of Pueblo Canyon downstream from Acid Canyon, a distance of more than 10 km. The part of the canyon floor containing plutonium above the background value ranges in width from less than 10 m to greater than 100 m. The horizontal and vertical extent of contaminated sediments are well defined in the reaches selected for geomorphic mapping and sampling and, if required, estimates of the extent of contaminated sediments in unsampled reaches could be made based solely on geomorphic mapping.

Concentrations of plutonium-239,240 in post-1942 sediment deposits show substantial variability both within reaches and between reaches, having a range of more than two orders of magnitude within some reaches. The highest concentrations of plutonium-239,240 and associated radionuclides occur in fine-grained sediments that were probably deposited concurrently with or soon after the peak contaminant releases from TA-45, and high variability in plutonium concentration also seems to exist within these deposits. These relatively old post-1942 sediments are found in geographically small areas that cannot be reliably identified using geomorphic mapping alone (e.g., the c2b unit in reach P-1 East and the c6 unit in P-4 West). However, if these isolated pockets of sediment are chosen as targets for remedial action to reduce potential risk, it would be possible to identify them in unsampled reaches using field measurements of alpha radiation in combination with geomorphic mapping.

Concentrations of most other radionuclides released from TA-45, specifically americium-241, plutonium-238, and possibly tritium, are positively correlated with the concentrations of plutonium-239,240, indicating that these COPCs are collocated with plutonium-239,240. Therefore, the areas of highest concentrations of these radionuclides can be predicted based on information on concentrations of plutonium-239,240 using either analytical data or field radiation measurements. Strontium-90 is also apparently elevated above background levels because of releases from TA-45, but it is not collocated with plutonium-239,240; therefore, the areas with the highest concentrations of strontium-90 cannot be predicted based on the plutonium data.

Inorganic and organic COPCs in Pueblo Canyon are probably contained within the same sediment deposits as the plutonium-239,240, but concentrations of the inorganic and organic COPCs are not clearly correlated with plutonium concentrations in post-1942 sediments. Because of their apparent lack of collocation with the primary radionuclide contaminants, it is not possible at present to systematically identify those sites where concentrations of inorganic and organic COPCs are highest. Therefore, if risk assessments identify that specific inorganic or organic COPCs require remedial actions, additional sediment sampling and analysis would be required to develop a defensible conceptual model that would describe the extent of contaminated sediment requiring remediation.

6.3 Potential Human Health Risk

The preliminary human health risk assessment presented in Section 5.1 evaluated the radiation dose that could be received by trail users, resource users, and construction workers in Pueblo Canyon under present-day conditions of contamination and land use. Only the dose contributed by plutonium-239,240 in sediments was evaluated in this report because a screening assessment indicated that this COPC was the dominant contributor to potential human health risk in Pueblo Canyon. The assessment indicated that nowhere in the Pueblo Canyon reaches did conservative estimates of dose exceed the preliminary remediation goal (PRG) of 15 mrem/yr proposed by the Environmental Protection Agency. Therefore, the results of this investigation indicate no immediate risk to human health because of the levels of contamination in Pueblo Canyon sediments and no need for immediate remedial action in the context of human health risk

The other COPCs that were identified in the human health screening assessment as having maximum values exceeding PRGs are the PAHs benzo(a)pyrene for all exposure scenarios; benzo(b)fluoranthene and dibenz(a,h)anthracene for both the trail user and the resource user scenarios; and mercury only for the resource user scenario. The PAHs may warrant additional sampling and analysis to determine if they are derived from Laboratory potential release sites (PRSs) or from elsewhere in the Los Alamos townsite, and possibly to better define their distribution and concentrations. For mercury, the pathway associated with the exceedances of the resource user PRG is uptake from sediments to plants and then from plants to meat. This scenario is conservative because the animals providing meat are assumed to range and graze exclusively on the contaminated sediments. This assumption needs to be evaluated by comparing the areal extent of mercury contamination in reach P-1, where the highest values occur, with the range requirements for typical grazing animals in this area.

The human health risk assessment presented in this report evaluated only the risk due to contaminants in sediments, and additional risk assessments will be required that incorporate surface water and/or groundwater exposure pathways. Data on water quality are currently being collected from Pueblo Canyon by the Environmental Restoration Project for use in these future assessments. Additional risk assessments may also be required to evaluate different land use and exposure scenarios, such as residential scenarios, if it is decided that such assessments are appropriate.

6.4 Potential Ecological Risk

Potential ecological risk is poorly defined in Pueblo Canyon because of the limited scope of the ecological screening assessment that was possible in the context of this report. Because the Laboratory has not compiled information on the toxicity of Pueblo Canyon contaminants of potential ecological concern (COPECs) to aquatic receptors or on the concentration of COPECs in surface water, the assessment presented in Section 5.2 evaluated only the potential risk to terrestrial receptors from contaminants contained within the sediments. In addition, this preliminary assessment used only maximum values obtained for each COPC within Pueblo Canyon and made no attempt to estimate average concentrations or to evaluate risk on a reach basis or a watershed basis. Despite these limitations, this assessment indicates that several contaminants present within the sediments of Pueblo Canyon pose potential ecological risk to terrestrial receptors and thus will require additional assessment;

this assessment also identifies some specific data needs. However, the lack of obvious contaminant-related ecological impacts in Pueblo Canyon suggests that there is no need for immediate remedial action with regard to ecological risk.

The screening assessment performed in this investigation identified mercury as presenting the highest potential ecological risk within the sediments of Pueblo Canyon. Available data indicate that mercury was released from multiple sites in the upper part of the Pueblo Canyon watershed and has its highest concentrations in reach P-1, although it has also been detected above background values in downstream reaches. At least two significant uncertainties exist concerning the potential ecological risk posed by mercury in Pueblo Canyon. First, the specific chemical form of the mercury is unknown, and the preliminary ecological risk calculations assumed that all the mercury is present in its most toxic form (methyl mercury). A more realistic ecological assessment of the risk posed by mercury could benefit from data on its actual chemical form and/or the actual biological uptake. A relatively simple first step in performing a more realistic assessment would be to determine the mercury valence states and compounds present within sediment samples in reach P-1, where mercury concentrations are highest. A second uncertainty concerns the geographic distribution of the mercury. Because mercury is not clearly collocated with plutonium-239,240, available data are insufficient to develop a conceptual model describing the distribution of mercury in enough detail to use in designing and implementing remedial actions, if these are required. Therefore, if further assessments indicate that mercury poses a significant ecological risk in Pueblo Canyon, additional sampling would be required to define the distribution of mercury and propose remedial actions.

Plutonium-239,240 was identified as the COPEC with the second highest potential ecological risk in the sediments of Pueblo Canyon. Geographic variations in plutonium concentration are well established in Pueblo Canyon, and available data are adequate in this regard to perform additional assessments and to propose remedial actions, if required. The largest uncertainty concerns the actual uptake of plutonium into the food web, and this uncertainty could be reduced through application of Laboratory-specific biota uptake studies or new investigations of plutonium in animal tissue.

The remaining COPECs that were identified as potential ecological risk drivers in this investigation in part share the same uncertainties associated with mercury (uncertain chemical form, biological uptake, and geographic distribution), although for some there are additional questions as to whether they were released from Laboratory operations. Data on these COPCs in sediments and/or animal tissues could be obtained concurrently with further investigations of mercury if required for future ecological risk assessment.

6.5 Future Remobilization and Transport of Contaminated Sediments

Floods constitute the primary transport mechanism for contaminants in Pueblo Canyon and, under natural conditions, floods will continue to redistribute these contaminants. Future effects of floods can be estimated based on the geomorphic record of the effects of floods that have occurred during the past 55 years. Each flood redistributes part of the contaminant inventory within the watershed and also mixes contaminated sediment with uncontaminated sediment derived from various parts of the watershed. This mixing of sediment from different sources has reduced the concentration of plutonium transported by floods over time. Plutonium concentrations in sediment transported during floods were highest during the period of active releases of radioactive effluent from TA-45, before 1965, and concentrations dropped rapidly after effluent releases stopped. Plutonium concentrations have been stable or have declined since that time; therefore, concentrations can be expected to remain stable or to decline during the next several decades. Thus, remedial actions to reduce plutonium concentrations in sediment transported during floods will be necessary only if it is determined that present-day concentrations pose a significant human health or ecological risk or are otherwise unacceptable.

Most of the plutonium contained within sediments in Pueblo Canyon is located in geomorphic units that are presently isolated from the active channel and that are not considered to be susceptible to remobilization by vertical channel incision or lateral bank erosion during the next 50 years, as discussed in Section 4.3.6. In addition, part of the plutonium that is remobilized will be redeposited in relatively stable geomorphic settings downstream within Pueblo Canyon and thus will not reach Los Alamos Canyon or the Rio Grande over these time scales. In the short term (next ten years), the plutonium most susceptible to transport off Laboratory property is believed to be contained within sediment deposits in reach P-4 in lower Pueblo Canyon, which is an area that is experiencing relatively extensive erosion at present, although less than 20% of the plutonium in P-4 is considered susceptible to remobilization. No immediate remedial action in reach P-4 is considered necessary because risk-based decisions and regulatory standards are based on concentrations of contaminants and not mass (inventory) and because the preliminary risk assessment results indicate that current concentrations do not pose unacceptable risks.

If it is determined that concentrations of plutonium or the total amount of plutonium in sediments leaving Pueblo Canyon are unacceptable, remedial actions would ideally be based on a model that describes the redistribution of sediment within and transport of sediment out of Pueblo Canyon. Such a model should allow an evaluation of the effects of various remedial actions over a variety of time scales and be tailored for the parameter of interest (i.e., concentration or mass). For example, if the desired goal is to reduce plutonium concentrations in sediment at the confluence with Los Alamos Canyon, remedial actions in one part of the canyon might be indicated, but if the goal is to reduce the total mass of plutonium leaving Pueblo Canyon over some time frame, different remedial actions might be warranted.

Currently it is not possible to quantitatively predict (1) the rate that plutonium and other contaminants will be transported out of Pueblo Canyon and into Los Alamos Canyon, (2) contaminant concentrations within sediments carried by future floods (except in the short term), or (3) the effects of possible remedial actions, although qualitative predictions can be made. Quantitative predictions would require a defensible model that can incorporate the remobilization of contaminated sediment from a variety of geomorphic units, which have variable sediment residence times; the mixing of sediment from both contaminated and uncontaminated sources; and the redistribution of this sediment by floods with varying recurrence intervals. Because of the probabilistic nature of floods, a probabilistic sediment transport model would be most appropriate. Therefore, if it is foreseen that remedial actions may be warranted in the future to reduce either the concentrations or mass of plutonium leaving Pueblo Canyon, development of a probabilistic sediment transport model tailored to the conditions in Pueblo Canyon should be pursued.

6.6 Summary of Recommendations

The assessments of potential human health and ecological risk presented in this report indicate that levels of contamination in the sediments of Pueblo Canyon do not require immediate remedial actions with regard to present-day risk. Similarly, the geomorphic assessments indicate that the concentrations of contaminants in sediments carried by floods have been stable or have declined for decades, and the redistribution of contaminated sediments will not result in future increases in contaminant concentrations in downstream areas. Therefore, no remedial actions are proposed at this time, although remedial actions may be warranted in the future following additional assessments.

Additional risk assessments will be required beyond what was possible in the context of this report, including both human health and ecological risk, and some additional sampling and analysis will be required to support these assessments. In particular, water quality data will be required for both human health and ecological risk assessments, and continued collection of sufficient data to perform risk assessments is considered a priority. In addition, more analyses from sediment samples may be required to complete these risk assessments. Goals of additional sampling may include determining the specific chemical form and sources of the mercury, and also determining the most significant source for the mercury. Additional goals of further sampling may include determining the source and distribution of PAHs. If it is decided that additional sediment sampling is required outside of the sampled reaches (e.g., closer to the Pueblo Canyon WWTP), then additional geomorphic mapping in these areas will also be required.

Decision points concerning the transport of contaminants from Pueblo Canyon into Los Alamos Canyon and toward the Rio Grande are not yet defined; thus, it is uncertain if remedial actions may be required to reduce either the concentrations of contaminants in sediments carried by floods or the total mass (inventory) of contaminants transported downstream over various time frames. Therefore, decisions concerning the possible need for remedial action in this context will depend on the development of specific decision criteria. However, if it is foreseen that remedial actions may be required in the future to address off-site transport, development of a defensible sediment transport model should be pursued that would allow better identification of specific sites where remedial actions would be most effective.

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